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A global assessment of fisheries bycatch and discards

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PREPARATION OF THIS DOCUMENT

The apparent waste of living resources represented by discards has negatively influenced the image of the fishing industry which must face the issue of selectivity in fishing gear and practices. These issues will be addressed in the FAO Code of Conduct for Responsible Fishing and particularly in its chapters related to fishing operations, management and research.

The present report presents, for the first time, a global and regional analysis of bycatch and discards in fisheries, by gear, target species and fishing areas prepared by Natural Resources Consultants, Inc., 4025, 21st Street, Suite 200, Seattle, Washington, 98199, USA, with support from FAO which has agreed to publish the report.

A majority of the 800 papers examined came from the northern hemisphere. The tropical areas were covered as well as the available information permitted, and it is hoped that the study will stimulate investigations on bycatch and discards in these areas.

A complete Bycatch Database, which was compiled for the study, and a summary of it, are distributed with this document on a DOS compatible diskette to allow the readers of the report to have access to the basic data for their own analysis.

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Distribution

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A global assessment of fisheries bycatch and discards.
FAO Fisheries Technical Paper. No. 339. Rome, FAO. 1994. 233p.

Summary

The authors estimate that between 17.9 and 39.5 million tons (average 27.0 million) of fish are discarded each year in commercial fisheries. These estimates are based on a review of over 800 papers. The highest quantities of discards are from the Northwest Pacific while tropical shrimp trawl fisheries generate a higher proportion of discards than any other fishery type, accounting for one third of the global total.

Of four major gear groups, shrimp trawls stand alone at the top of the list; bottom trawls, long-lines and pot fisheries come next. The third group consists of Japanese high-seas drift net fisheries, Danish seines and purse seines for capelin. Relatively low levels result from pelagic trawls, small pelagic purse seines and some of high seas drift nets. The authors point to inadequate data to determine the biological, ecological, economic and cultural impacts of discards although economic losses run to billions of dollars. However, it appears most likely that socio-cultural attitudes towards marine resources will guide international discard policies.

Techniques to reduce bycatch levels including traditional net selectivity, fishing gear development and time/area restrictions, are discussed. Effort reduction, incentive programmes and individual transferable quotas (that make the vessel responsible for bycatch reduction) are seen as promising avenues for the future. However, quick solutions to the problem are unlikely and much more information is required.

The publication includes a diskette with the complete Bycatch Database, which was compiled for the study, and a summary of it.

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EXECUTIVE SUMMARY

The authors have examined several hundred articles concerned with bycatch and discards in world fisheries. Over 800 papers containing quantitative and qualitative information were used to characterize the nature and scope of regional and global bycatch problems. Mortalities associated with discarding practices were also reviewed.

The authors provide a provisional estimate of global discards in commercial fisheries of 27.0 million mt with a range of from 17.9 to 39.5 million mt. The region with the highest discard estimate is the Northwest Pacific. Shrimp trawl fisheries, particularly for tropical species, were found to generate more discards than any other fishery type and account for just over one-third of the global total. On a weight per weight basis, fourteen of the highest 20 discard ratios were associated with shrimp trawls. The fisheries associated with the twenty highest numbers-based ratios represented a more eclectic mix of shrimp trawl, pot, fish trawl, and longline fishery gear types. At the opposite end of the scale, fish trawl, seine, and high seas driftnet fisheries accounted for the majority of the gear types in the authors' list of the ten lowest discard ratios.

It should be noted that although data are tremendously variable, four major gear groups stand out. Shrimp trawls are alone at the top of the list, while relatively low levels are recorded for pelagic trawls, purse seines targeting on menhaden, sardines, and anchoveta, and some of the high seas driftnet fisheries. Between these two extremes lie two other groups. The first of these is comprised of bottom trawls, unspecified trawls, longline gear, and the majority of the pot fisheries. The final group fits between the very low ratios of the pelagic trawl group and the moderate ratios of the aforementioned bottom trawl/pot/line assemblage. Fisheries in this last group include the Japanese high seas driftnet fisheries, Danish seines, and purse seines for capelin.

The authors note there is in most instances inadequate data to determine the real biological, ecological, economic, or socio-cultural impact of discards. Nevertheless, data do suggest that survival of most discarded species is low, declines in some non-target species have been significant, overfishing often involves a significant discard component, and shifts in species dominance and the occupation of certain ecological niches have been in part due to discarding. The extent to which discarding alone and not the fishing process as a whole is responsible for these shifts is, however, unclear.

Economic losses tied to the act of discarding and objectives of monitoring or preventing discards presently run into billions of dollars. Such losses include those associated with discards of species of commercial value to other fisheries, discards

of non-legal individuals (for reasons of sex, size, or management policy), and indirect costs related to discarding of non-target species of little commercial value. Included in the bundle of monitoring and prevention costs are bycatch-related marine fisheries management expenditures, lost fishing opportunity due to premature target fishery closures following the attainment of bycatch caps, observer costs, enforcement expenses, modifications to fishing behavior, and increases in sorting and handling times.

The authors feel socio-cultural attitudes toward marine resources should be an important consideration in the development of international discard policies. Unfortunately, to date the policy process has paid too little attention to socio-cultural perspectives which are often influenced by differing national dependencies on marine resources as a protein staple. The authors also note the growing importance of non-consumptive uses to fisheries and bycatch policy changes. They urge evolution of global discard policies be ear-marked by the minimization of social conflicts, be independent, to the degree possible, of ideological differences, and be based on sound conservation principles.

Case studies are provided for bycatch and discard problems in the Northeast Pacific, as well as the Northeast and Northwest Atlantic. Bycatch and bycatch issues have been intensively studied in these locations relative to other areas. In the Northeast Pacific, a suite of fisheries produces a bycatch total exceeding one billion individuals annually. Impacts appear low on most species except the Pacific halibut and possibly king and Tanner crab.

Discard problems in the Northwest Atlantic were classified into four groups: (1) marketable species too small or otherwise prohibited from landings, (2) species for which no current market exists, but are caught along with commercial or recreational species, (3) species-specific fleet sectors discarding another fisheries target species, and (4) non-fishery bycatch species, including marine mammals, turtles, and birds. Regulatory approaches and management actions to address these problems are also discussed.

The section covering the Northeast Atlantic focuses on discarding in the mixed-species trawl fisheries for North Sea gadoids. The impact of discards on mortality rates for haddock and whiting and the effect of reductions in fishing effort draw particular scrutiny. Most of the discard problems noted in earlier chapters pertaining to North American fisheries are also noted in the fisheries of the Northeast Atlantic. Local variations associated with misreporting and environmental effects are, however, discussed. Also provided is a review of regulatory and gear management measures commonly applied in the region. The authors point out that many supposed technical solutions can generate unsuspected side effects which may impair their effectiveness. Further, they remind the reader voluntary bycatch reduction

measures are unlikely to be successful if they are not in the short-term economic interest of the affected fisher.

A variety of techniques have been attempted by managers, engineers, and scientists to reduce bycatch/discard levels. These have included traditional net selectivity approaches, the development of fishing gear taking advantage of differential species behavior, and time/area fishing restrictions. These methodologies have worked with varying degrees of success depending on the species being managed and the willingness of industry to work together for positive solutions.

Emerging ideas include effort reduction, incentive programs, and individual transferable quotas that move the responsibility for bycatch reduction to the individual vessel level. The authors feel major gains against the global bycatch problem are likely to occur as such shifts towards individual responsibility take place. Progress may be impeded, however, because observer programs, an uncommon characteristic of today's fisheries, are necessary to audit progress toward bycatch goals adequately. For many fisheries suffering from growth overfishing, a reduction in effort may be the most straightforward means of reducing bycatch and improving fisheries conservation and management. Because the solution to global discard problems will vary between fisheries and regions, a clear understanding of the nature and scope of specific fishery problems should precede the introduction of management and other measures.

In the final chapter of the report, the authors scrutinize their work, remind the reader of particularly noteworthy findings, and discuss weaknesses in an analysis of the proportions associated with a global review. They also point out that actual data are often at odds with common perceptions and that many commercial and recreational fishers see bycatch as someone else's problem when, in fact, it is an all too common heritage. Finally, the authors note the many inconsistencies and inadequacies associated with current bycatch data and call upon the scientific community to work toward standardizing data presentation, if not collection, formats. In saying that, however, the authors recognize particular numbers and ratios may have little to do with actual ecological impacts. Consequently, they encourage heightened scientific attention to the assessment of population, community, and ecosystem impacts, in conjunction with improvements in our quantification of bycatch and discard losses.

Quick solutions to the bycatch problem are unlikely. Instead, a concerted national and international effort that will take money and time is necessary. A critical component of such action will be the reduction in effort levels from today's excessive amounts to quantities which will avoid conservation and ecological problems and will efficiently harvest the sea's resources.

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GLOSSARY

ADF&G - Alaska Department of Fish and Game (U.S.)
DANIDA - Danish International Development Agency
DFO - Canadian Department of Fisheries and Oceans
EEZ - Exclusive Economic Zone
ETP - Eastern Tropical Pacific
FAO - Food and Agriculture Organization
FCMA - Fisheries Conservation and Management Act (U.S.)
FFA - Forum Fisheries Agency
IATTC - Inter-American Tropical Tuna Commission
ICCAT - International Commission for the Conservation of Atlantic Tunas
ICES - International Council for the Exploration of the Sea
ICLARM - International Center for Living Aquatic Resources Management
IDCA - International Dolphin Conservation Act
IFC - International Fisheries Commission
INPFC - International North Pacific Fisheries Commission
IPHC - International Pacific Halibut Commission
IUCN - International Union for the Conservation of Nature
IWC - International Whaling Commission
MFCMA - Magnuson Fisheries Conservation and Management Act
MMPA - Marine Mammal Protection Act (U.S.)
MSY - Maximum Sustainable Yield
NAFO - Northwest Atlantic Fisheries Organization
NMFS - National Marine Fisheries Service (U.S.)
NOAA - National Oceanic and Atmospheric Administration (U.S.)
NRC - Natural Resources Consultants, Inc. (U.S.)
NRI - Natural Resources Institute (U.K.)
ODA - Overseas Development Administration
PSC - Prohibited Species Catch
SPC - South Pacific Commission
UN - United Nations
UNCED - United Nations Conference on Economic Development
UNCLOS - United Nations Convention on the Law of the Sea
UNGA - United Nations General Assembly
USFWS - United States Fish and Wildlife Service

INTRODUCTION

The at-sea discarding of fish harvested from the ocean and its associated mortalities have been recognized and noted by fisheries scientists as inherent problems in the management of world fisheries since early in this century. Indeed, references pertaining to bycatch that date back to biblical times can be found (Matthew 13:47-48):

> Again, the Kingdom of Heaven can be illustrated by a fisherman, he casts a net into the water and gathers in fish of ever kind valuable and worthless. When the net is full he drags it up onto the beach and sits down and sorts the eatable ones into crates and throws the others away.

Programs and techniques that try to reduce bycatch are not new, either. Introduction of mesh regulations to reduce the catch of undersized target species constitutes a long-accepted management technique introduced into Western European (ICES[1] 1971, 1975; Jermyn and Robb 1981; Commission of European Communities 1991; Caddy 1989) and North American (Freeberg 1992) fisheries early in this century. Voluntary actions were probably taken much earlier by fishermen attempting to reduce sorting of bycatch. For many years, countries have set minimum mesh sizes for nets and, at times, for pots, traps, and other gear to minimize catches of juveniles. Such regulations were frequently coupled with minimum size and time/area restrictions (Commission of the European Communities 1991). Further, many states have also introduced or passed legislation limiting harvest methods and operational modes for selected waters and regions. Thus, bycatch and associated discards, as well as programs attempting to resolve them, are not new phenomena.

What is new, however, is the almost explosive interest taken over the past decade in the documentation and search for solutions to bycatch problems. To a considerable degree, this sudden interest has followed the phenomenal growth of world conservation and environmental groups and their early interest in the consequences of fishing activities on populations of marine mammals, birds, and turtles (Alverson 1992a; Bricklemyer 1989/1990; Murray et al. 1992; Northridge 1991a, 1991b).

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[1] Full names for all acronyms used in this report are presented in the glossary.

In the early 1980s numerous bycatch papers surfaced regarding levels of discards in world shrimp fisheries (Allsopp 1982; Caddy 1982; Campos 1981; Grantham 1980; Sheridan et al. 1981; Slavin 1982; Sternin and Allsopp 1982). Saila (1983), noting that anticipated demand for edible fish would double between 1979 and the year 2000, prepared a detailed report on world bycatch and discard levels for the Food and Agriculture Organization of the United Nations (FAO). In the report, Saila estimated a minimum world discard of fish and shellfish of about 6.72 million metric tons (14.8 billion pounds). It is clear from Saila's report, however, that only minimal or partial data were available on many marine species groups, and no information is summarized on bycatch of higher trophic level forms (marine mammals, birds, and turtles). Nevertheless, Saila's work was the first comprehensive examination of bycatch and was an "eye-opener" in terms of the potential losses (mortalities) occurring as the result of discards in world fisheries.

Since the publication of Saila's work and particularly at the onset of this decade, the documentation of bycatch levels, search for solutions to reduce discard levels, and evolution of management strategies to deal with bycatch has increased rapidly and become a focal point of world fishery management. An in-depth review of bycatch problems covering Northeast Pacific trawl fisheries was published in 1984 by Natural Resources Consultants, Inc. (NRC 1984). This review was followed by a comprehensive documentation of the "Nature and Scope of Fisheries-Dependent Mortalities" for a variety of Northeast Pacific fisheries (NRC 1990). Bricklemyer et al. (1989/1990), in the *Audubon Wildlife Report*, discussed the broader aspects of discarded catch in U.S. commercial fisheries, and more recently Andrew and Pepperell (1992) estimated a global bycatch in world shrimp fisheries as high as 16.7 million mt. The growing importance of bycatch in world fishery management is further reflected in the increased attention paid to this topic by international ocean-oriented bodies, such as ICES, IPHC, INPFC, FAO, IWC, and IATTC, throughout the 1980s and continuing into this decade.

By the early 1990s, bycatch had become a topic of global attention at various international forums, such as the World Fisheries Congress in Athens, Greece, May 1992; the Symposium on Fish Behavior in Relation to Fishing Operations Workshop in Bergen, Norway, June 1992; the International Conference on Responsible Fishing in Cancun, Mexico, May 1992; the NAFO Symposium on Gear Selectivity, Dartmouth, Nova Scotia, Canada, 1993 , and later at the Brazil UNCED meetings. During this period, bycatch and discards also became the subject of discussion at a variety of national workshops and conferences in North America, Europe, Asia, Australia, and elsewhere (Schoning et al. 1992; International Conference on Shrimp Bycatch 1992; Sissenwine and Daan 1991; Commission of the European Communities 1991). The increasing importance of bycatch issues did not escape the world press, of course, and a rash of articles concerned with biological damage and waste in fisheries added momentum to U.S. and United Nations efforts to eliminate high seas driftnetting (gillnetting) from the North and South Pacific (Northridge 1991a; Burke et al. 1993). The media's recent

characterization of waste in world fisheries has helped create the image of fishing as a "dirty" industry. Robin Alden (1992), publisher and editor of *Commercial Fishing News* (Stonington, Maine, U.S.A.), noted:

> The tide of public opinion has turned against commercial fishing. Whereas before, the industry was either invisible and ignored, or seen as something desirable, it is now being seen as an extractive industry. We have become "industry" instead of a proud, renewable, and thus environmentally sound, way of making a living.
>
> ...the barrage of negative publicity focuses the choice before us. Are we going to be an extractive industry paying for the power in Washington and state capitols to try to continue to operate unfettered? Or are we going to grapple with the dirty side of the business, clean up our act, and then be able to defend with pride our right to exist at whatever scale is appropriate for a given fishery?

Murawski (1992), reflecting on the growing bycatch problem, states:

> Bycatch interactions have been and remain almost the most frustrating, difficult, and time-consuming problems faced in fisheries management areas throughout the world (Hobson and Lenarz 1977; Mercer 1982; Pikitch 1988). Although bycatch has always been an integral part of fishing with non-discriminative gear, efforts to manage bycatch effectively have intensified (Dewees and Ueber 1990; Murawski 1991; Daan and Sissenwine 1991).

Given changing public perceptions of fishing and the complexity of the bycatch discard issue, better information is needed if we are to address the management problems introduced by bycatch. In recent years greater efforts have occurred to document the body of scientific data concerning quantities of bycatch, levels of discards, survival of discards, and impacts of losses resulting from discards on target and non-target marine populations. Nevertheless, we are still at an early state of understanding the regional and international biological/ecological and economic consequences of discarding, its impact on ecological communities, and the means to reduce discard levels in order to maintain the productivity of the world's ocean fisheries. Not surprisingly, individuals, fishery and environmental organizations, and national and international government perspectives differ significantly in terms of the need for bycatch management and how best to go about it.

It is the purpose of this study to summarize current knowledge concerning the quality and quantity of bycatch and discards in world fisheries, the biological, ecological, and economic consequences of discarding, and the scientific, socio-economic, and political bases of current national and international bycatch management strategies and to evaluate alternative solutions. The paper first reviews terminology used in the scientific literature and establishes operational definitions

for terms used in this study. The subsequent aspects of this major chapter examine the database available regarding world bycatch and discard levels, make provisional estimates of discard ratios by gear type and region, and conclude with a global estimate of world discards. Subsequent chapters of the paper examine the potential impacts of discards as they relate to biological/ecological, economic, and sociological factors, and regional overviews for the Northeast Pacific, Northwest Atlantic, and the Northeast Atlantic. The final chapters examine the evolution of bycatch policy and solutions designed to reduce bycatch levels and present a general discussion of the paper's key findings and recommendations.

PART I

ESTIMATES OF GLOBAL FISHERY BYCATCH AND DISCARDS

CHAPTER 1 ESTIMATES OF FISHERIES BYCATCH AND DISCARDS

Terminology

In scanning the literature concerned with bycatch and discards in world fisheries, it quickly becomes apparent the term "bycatch" has meant and continues to mean different things to different investigators. Furthermore, operational definitions of what is meant by bycatch are frequently not available in the published literature.

From our review of the literature, we conclude that "bycatch" has customarily been used to identify (1) species retained and sold, (2) species or sizes and sexes of species discarded as a result of economic, legal, or personal considerations, and (3) non-targeted species retained and sold, plus all discards. These terms may be further constrained in that within any one of these three categories authors may select and discuss only a portion of the bycatch caught with a particular gear type.

The first definition has been used by various investigators to differentiate target species from other species caught and retained. Australian authors have used the term "by-product" to refer to this form of bycatch. The second definition has generally been used by scientists reporting on fisheries of the Northeast and Western Pacific. A variety of scientists in other areas of the world have used the third definition which is consistent with that used by Saila (1983). In a few instances the term "joint catch" appears to have been used interchangeably with "bycatch" (Dewees and Ueber 1990).

Murawski (1992) states "the use of the term bycatch adds considerable confusion to a topic that is already complex to both scientists and managers." He notes the term is relatively imprecise in that it constitutes a value judgment and may be inaccurate when used over any extended time to describe an element within a multi-species catch--in essence, "yesterday's bycatch may be today's target species." During any specific fishing activity, the decision to set gear is often based on the expectation of harvesting a particular species. However, in other instances there may be no single target species in mind, the decision to fish being based on the anticipated value of the expected catch complex. Fishermen frequently make such choices based on the composition of past sets or the fishermen's collective experiences. It would appear the need to identify secondary target species as bycatch emerged from the desire of fishery statisticians to allocate

fishing effort to different elements of a catch complex--perhaps justifiable from the researcher's requirements, but inappropriate in terms of the reality of many multi-species fishing practices.

Unfortunately, the term "bycatch" has taken on a much different connotation, in recent years. To many conservation, environmental, and fishery groups and to the lay public, bycatch is synonymous with "waste" and the catch of marine mammals and other "high profile" sea life.

Operational Definitions

Concerns with the terminology used to identify bycatch or discards were addressed at a bycatch workshop in Newport, Oregon (U.S.A.) in February 1992 (McCaughran 1992). The authors have decided to use the following definitions as proposed at the Newport Workshop as operational definitions within this monograph:

Target Catch -- The catch of a species or species assemblage which is primarily sought in a fishery, such as shrimp, flounders, cods.

Incidental Catch -- Retained catch of non-targeted species.

Discarded Catch -- That portion of the catch returned to the sea as a result of economic, legal, or personal considerations.

Bycatch -- Discarded catch plus incidental catch.

Incidental Catch Rate -- The proportion of total catch which is incidental catch.

Discard Rate -- The proportion of total catch which is discarded. Rates may be computed for individual species or combined groups of species (Units of Measure--UM: kg/mt, numbers/mt, numbers/number, etc.).

Discard Mortality Rate -- The proportion of the discarded catch that dies as a result of catching or handling processes.

Discard Mortality -- Discard mortality rate multiplied by discarded catch.

Prohibited species -- Any species which must, by law, be returned to the sea.

Unobserved Fishing Mortality -- Mortality imposed on a species by the encounter with fishing gear that does not result in capture.

High-Grading -- The discard of a marketable species in order to retain the same species at a larger size and price. The discard of a marketable species in order to retain another species of higher value. The retention of only those species or individuals within a species complex having the greatest market value; less valuable species or individuals are discarded.

Individual Discard Quota (IDQ) -- A quantity of prohibited species which is initially apportioned amongst individuals or groups of individuals to allow effective harvest of non-prohibited species. The IDQ may or may not be traded/sold within this group or between this group and other groups.

Discard Quota -- An amount of a prohibited species allowed to be caught by a particular gear type before constraining a fishery. It may be the sum of all IDQs if such a system were in place.

Discard Mortality Quota -- The discard quota multiplied by the discard mortality rate.

It should be noted that the definitions adopted for bycatch and discards are consistent with those used by Saila (1983). To the above list the authors have added the following operational definitions for terms used in this paper:

Discard ratio -- The ratio of discard to actual retained catch (e.g., discard/retained catch frequency given as a percentage).

Unobserved fishery mortality -- Death resulting from fishing that cannot be documented from observations of the on-board catch (e.g., deaths resulting from fish passing through webbing, freeing themselves from hooks, ghost fishing, etc.).

Black fish -- Non-reported catch.

Grey fish -- Catch which is misreported as to area or species.

However, a litany of new terms is emerging in the bycatch literature which needs to be standardized. For example, terms identified in the Proceedings of the National Bycatch Workshop in Newport, Oregon, are similar to terms used in Europe, but some differences in nuance exist.

Discarded Catch--usually shortened to discards in European discussions, is widely perceived as a problem of fisheries management. For the most part,

this is seen as an economic waste of the species which are a scarce commercial resource. The problem of discarding of endangered species had not been viewed particularly seriously until recently. However, this is rapidly changing with the "wall of death" stories acting as a catalyst. It seems helpful to partition any discussion into considerations of commercial discards and of mortalities generated on non-commercial and, in particular, on potentially endangered species. These latter categories are often referred to as non-target mortalities.

Additional terms not covered in Newport are in use in the Economic Community. For example, the question of what is the target and what is the incidental catch is only resolved in Economic Community fisheries when the fishery operates under a legal derogation from the main regulations in force. Under the common fisheries policy of the EC, a number of derogation fisheries are allowed. These permit the use of smaller mesh sizes than the standard regulation, but often restrict the landed catch to certain minimum catch rates of named target species or maximum landed bycatches of named bycatch species. A problem this creates of particular concern to commercial fishermen is the bycatch of small commercial fish in the industrial fisheries (fisheries catching small species such as sandeel (sandlance, *Ammodytes* spp.) for reduction to fish meal and oil). Thus, Industrial bycatch[2] may deserve a category of its own.

Terms often encountered in the ETP tuna seine fishery include rejects (part of the catch that is not landed because of quality) and collateral mortality (similar to unobserved fishing mortality). Clearly, considerable differences in the use of the term bycatch and its associated terminology prevail regionally and a need exists, as the documentation and evaluation of bycatch and discards continues, to standardize terminology and observational modes.

Data Sources

Numerous entities have been contacted in an attempt to prepare an exhaustive set of references on discard rates and problems. These sources included individual scientists whose interest in bycatch was reflected in their publications in the subject area, national fishery entities throughout the world, international fisheries bodies (IWC, ICES, ICLARM, IATTC, IPHC, FFA, SPC, ICCAT, IFC, FAO and its field programs), and selected universities throughout the world. These sources and others were contacted in order to secure qualitative and quantitative data on the character and magnitude of discards occurring in various fisheries of the world.

In conducting our literature search, the multiple meanings of the term "bycatch" at times made it difficult to acquire relevant information regarding

[2] Industrial bycatch is the bycatch resulting from fisheries for species rendered into meal and oil.

discards, especially total quantities and the biodiversity of discards from particular fishing activities. After a period of data collection and literature search extending over more than two years, the authors have accumulated and reviewed an extensive literature base concerned with discards occurring in world fisheries and scanned thousands of abstracts and noted references concerning bycatch. The papers and articles gathered on bycatch have been placed in a special collection within the library of NRC in Seattle, Washington.

Articles received by NRC were first reviewed for their relevance to the bycatch topics (discard levels) under consideration in this study. Relevant documents were assigned a unique reference number and logged into *FileMaker®*, a computerized library and information retrieval system. Reference numbers were stored in *FileMaker®*, along with eight separate fields for article and publication titles, author name(s), date and type of publication, keyword lists, species discussed in the article, and the location of the study area/fishery. Principle target and bycatch species discussed in the article were recorded in the species field. In the location field, FAO fishery region and specific sub-areas or countries within each region where the work was focused were listed. The design of the *FileMaker®* system permits searching in any one or more of the nine information fields. Search times for a specific reference in the database typically requires two or three seconds. Reference numbers assigned to each article by *FileMaker®* were recorded on the top left-hand corner of the cover page of each hardcopy document when it was stored in the NRC library.

Database Characteristics

In our development of regional and global bycatch and discard estimates, the authors have reviewed some 820 papers pertaining to all aspects of the bycatch problem. To chronicle this review, a world bycatch database was created using a commercial computer spreadsheet program. Nineteen unique types of information were recorded in this database for each reviewed article. This information was recorded using discrete columns containing study year, FAO region, sub-region or area, fishing nation, gear type, target species or species complex, bycatch or discard species type, weight and/or number of discards, weight and/or number of the target species, and four calculated columns which derive discard per target species on a number per number, number per weight, weight per number, and weight per weight basis using data elsewhere in the subject row. Three additional columns denote whether the discard values refer to discards or more generically to bycatch, the ratio of total retained weight or number to target species weight or number, and the reference number assigned to the article and recorded in *FileMaker®*. A final note field was used for short qualitative descriptions of key characteristics of the target or discard data contained within the article.

The nature of computer spreadsheet programs and the structure of the world bycatch database permit a number of sorts, extractions, and other database manipulations allowing access to bycatch discard data of specific interest to a given user. For example, bycatch data pertinent to particular areas, gears, or species can be acquired by sorting by each of these fields individually. Likewise, discards of a given **species** by a certain **gear type** in selected **areas** can be reviewed by using all three of these fields when sorting. Total retained weight or number can be calculated by multiplying target weight or number by the ratio of total retained to target weight or number. Discard ratios for individual species within a fishery can be obtained directly from the database. Qualitative information recorded in the notes field can contain important insights into the quantitative discard data recorded for each fishery and should be consulted by each user (Figure 1 and Table 1).

The bycatch database emerging from this review currently contains more than 1,700 records and continues to grow as new documents are added to the NRC bycatch library. A sample page from the database is included as Figure 1. Table 1 contains a list of fishery, area, and species codes used in the database. Of the records in the database, 1,012 contain quantitative assessments of discards on an area/gear/target and non-target species basis. The remaining 711 records contain qualitative information pertaining to one or more of the many questions (economic, biological, ecological, social, legal, and ethical) surrounding the bycatch issue.

Bycatch and discard data reported for various regions and fisheries differ from fishery to fishery. Acquired target and non-target data are most frequently given in the form of numbers or weight and less frequently in terms of CPUE. Most authors report discards as a function of catch retained, e.g., the ratio of numbers discarded to numbers retained or the ratio of weight discarded to weight retained. Others report numbers discarded per retained weight of target species. Studies classifying target and non-target catch by numbers and weight or providing a ready means of converting one measure into the other were rare. Recognizing the diverse characteristics of the recorded observations, the NRC bycatch database was designed to permit entry of either or both data types. A total of 727 weight-based records and 285 numbers-based records currently reside in the system. Of these records, 100 contain target and non-target data quantified in terms of both numbers and weight.

Count	Period	FAO Region	Area	Fishing Nation	Gear	Target Species	Discard Species	Discard Number	Discard Wgt (mt)	Retained Target Number	Retained Target Wgt (mt)	Discard Number per Target Number	Discard Number per Target Weight	Discard Weight (mt) per Target Weight (mt)	Retained Total per Target	Source Reference Number
277	1988	27	35	26	6	40	52	12,092	NS	65011.00	208.00	0.186	58.135	#VALUE!	1	153
278	1989	27	35	26	6	40	52	10,004	NS	93496.00	309.00	0.107	32.375	#VALUE!	1	153
279	1990	27	35	26	6	40	52	11,811	NS	111425.00	361.00	0.106	32.717	#VALUE!	1	153
280	1987	27	35	26	6	40	52	10,102	NS	140304.00	539.00	0.072	18.742	#VALUE!	1	153
281	1986	27	35	26	6	40	52	2,782	NS	154554.00	545.00	0.018	5.105	#VALUE!	1	153
282	1985	27	35	26	6	40	52	18,330	NS	135776.00	598.00	0.135	30.652	#VALUE!	1	153
283	1984	27	35	26	6	40	52	4,856	NS	124508.00	651.00	0.039	7.459	#VALUE!	1	153
284	1982	67	1	1	11	41	48	4,200,000	4,609	541009.00	1361.00	7.763	3085.966	3.387	1	154
285	1983	67	1	1	11	42	48	3,658,810	4,019	2286756.00	2392.00	1.600	1529.603	1.680	1	154
286	1982	67	1	1	11	42	48	7,729,568	8,390	4830980.00	4994.00	1.600	1547.771	1.680	1	154
287	1981	67	1	6	6	3	48	6,935	5	NS	10100.00	#VALUE!	0.687	0.000	1	154
288	1982	67	1	6	6	3	48	6,898	6	NS	12637.00	#VALUE!	0.546	0.000	1	154
289	1980	67	1	6	6	3	48	11,034	7	NS	12825.00	#VALUE!	0.860	0.001	1	154
290	1981	67	1	1	11	42	48	19,019,541	22,656	11887213.00	13486.00	1.600	1410.317	1.680	1	154
291	1981	67	1	1	11	41	48	46,600,000	45,224	5307947.00	15237.00	8.779	3058.345	2.968	1	154
292	1980	67	1	1	11	42	48	23,462,914	27,859	14664321.00	16583.00	1.600	1414.878	1.680	1	154
293	1979	67	1	1	11	42	48	26,762,429	32,422	16726518.00	19299.00	1.600	1386.726	1.680	1	154
294	1977	67	1	1	11	42	48	32,402,413	39,211	20251508.00	23340.00	1.600	1388.278	1.680	1	154
295	1978	67	1	1	11	42	48	42,025,115	50,623	26265697.00	30133.00	1.600	1394.654	1.680	1	154
296	1977	67	1	1	11	41	48	97,100,000	99,966	11733101.00	31737.00	8.276	3059.520	3.150	1	154
297	1980	67	1	7	3	3	48	289,540	241	NS	31800.00	#VALUE!	9.105	0.008	1	154
298	1978	67	1	1	11	41	48		125,633	14745709.00	39743.00	#VALUE!	#VALUE!	3.161	1	154
299	1979	67	1	1	11	41	48	139,400,000	143,209	16808605.00	48910.00	8.293	2850.133	2.928	1	154
300	1980	67	1	1	11	41	48	172,600,000	177,602	20845350.00	58944.00	8.280	2928.203	3.013	1	154

Figure 1. Example records of the world bycatch database

Table 1. Key of fishery, area, and species codes pertaining to the world bycatch database.

	FAO Region	Area	Fishing Nation	Gear	Target	Bycatch Sp	
1	See FAO	Bering Sea	US	Bottom Twl	Pollock-32	Juvenile Chinook	1
2	Codes	Gulf of Alaska	Canada	Pelagic Twl	Pacific cod-32	Chinook	2
3	99=All	Brit. Columbia	Japan	Unsp. Twl	Groundfish	Coho	3
4	999=All US	West Coast	Taiwan	Gillnet	Squid-57	Sockeye	4
5		N.Pac High Seas	Korea	HS Driftnet	Other Salmon-23	Pink	5
6		Iceland	Unsp Foreign/Various	Longline	Whiting-32	Chum	6
7		Baltic	JV (US/For)	Purse Seine	Halibut-31	Unsp Salmon	7
8		Irish Sea	Iceland	Troll	Atka mackerel-33	Steelhead	8
9		North Sea	Poland	Sport	Rockfish-33	Atlantic cod	9
10		W. Greenland	Ireland	Seine (Danish)	Yellowfin sole-31	Herring	10
11		NAFO 0A	Denmark	Trap/Pot	Deep-water Flatfish-31	Whiting	11
12		NAFO 3LNO	Scotland/England	Seine	Shrimp-45	Nephrops	12
13		NAFO 3L	Germany	Beam Trawl	Sprat-35	Various Spp	13
14		NAFO 2	Greenland	Various	Nephrops-43	Haddock	14
15		NAFO 3M	Portugal	Dredge	Atlantic cod-32	Hake	15
16		Scotian Shelf	USSR	Jig	Haddock-32	Plaice	16
17		Senegal	Italy		Dab-31	Dab	17
18		Guyana	Norway		Plaice-31	Pout	18
19		Hawaii	France		Capelin-34	Misc. Flounder/Sole	19
20		France/Gulf of Lions	Greece		Redfish-33	Turbot	20
21		Sicily	UK		Hake-32	Sole	21
22		Greece	Spain		Unsp Demersal-31	Shrimp	22
23		Celtic Sea	Holland/Netherlands		Lobster, Spiny-43	Greenland Halibt	23
24		Bay of Biscay	Australia		Lobster, Slipper-43	Redfish	24
25		ICES VI, VII, VIII	Faeroese		Lobster, American-43	Shark	25
26		Australia	New Zealand		Swordfish-36	Capelin	26
27		Newfoundland	India		Unspecified	R. Grenadier	27
28		New England	Malaysia		Sardine	Pollock	28
29		Gulf of Mexico	EEC (ICES)		Herring-35	Lobster, Spiny	29
30		Atlantic Canada	Philippines		Megrim	Lobster, Slipper	30
31		Southeast US	China		Mackerel-37	Lobster, American	31
32		Norwegian Sea	Mexico		Pout-32	Swordfish/Billfish	32
33		E.Trop. Pacific	Sri Lanka		Sole-31	Marlin	33
34		Southeast AK	Indonesia		Tuna-36	Tuna	34
35		Faeroe Islands	Arabian Gulf		Flounder-31	Turtles	35
36		New Zealand	Thailand		Opakapaka	Cetaceans/Pinnipeds	36
37		India	Trinidad		POP-33	Birds	37
38		Great Lakes	IATTC		Misc Flounder/Sole-31	Dogfish	38
39		Malaysia	Kuwait		Sablefish-33	Halibut	39
40		ICES IV	Guyana		Atlantic salmon-23	Skate/Rays	40
41		ICES IVa	Mozambique		King crab-42	Sardines	41
42		Philippines	Liberia		Tanner crab-42	Anchovies	42
43		Tasman Sea	SADDC (Southern Africa)		Whitefish-32	Mackerel	43
44		Sub-Trop Convergence	Senegal		Drum	Var. Bony Fishes	44
45		China	Brazil		Hoki-32	Var. Cephalopods	45
46		Mexico	Oman		Scallops	Opakapaka	46

Table 1 (continued).

	FAO Region	Area	Fishing Nation	Gear	Target	Bycatch Sp	
47		Sri Lanka	Peru		Castanha Family	Tanner crab/Other Crab	47
48		Indonesia	Virgin Islands		Ceteceans	King crab	48
49		Italy	Bangladesh		Horse Mackerel-34	Sculpin	49
50		Arabian Gulf	Sweden		Menhaden-35	Var. Crustaceans50	
51		Thailand			Crab, Unspecified-43	Pacific cod	51
52		Japan			Eel-22	Atlantic salmon	52
53		Gulf of Paria			Greenland Turbot-31	Monkfish	53
54		Caribbean			Rock sole-31	Scallops	54
55		New Caledonia			Shallow flatfish-31	Squid	55
56		West Central Africa				Sablefish	56
57		California				Pomfret	57
58		West Trop. Pacific				Weakfish	58
59		Gulf of California				Butterfish	59
60		New Brunswick				Snapper	60
61		Persian Gulf				Striped bass	61
62		Southern Oceans				Horse mackerel	62
63		South China Sea				Trout	63
64		Mozambique Channel					64
65		Gulf of Mannar					65
66		Medittereanean					66
67		Southern Africa					67
68		Rio Grande del Sol					68
69		Gulf of St. Lawrence					69
70		Southwest Atlantic					70
71		Indian Ocean					71
72		West Central Atlantic					72

Trawl fisheries account for 571 of the weight-based and 75 of our numbers-based entries. Net fisheries (driftnet, gillnet) are the second most common gear type in the database and account for 107 numbers-based and two weight-based records. Fifty-eight weight-based entries are linked to line fisheries. Line fisheries also contribute 33 numbers-based records. Weight- and numbers-based entries are more evenly split for pot gear, with 56 weight-based values and 41 numbers-based records. Table 2 displays the total number of database records and the number of records in weight- and numbers-based formats for each gear type. The "total" column involves records containing quantitative or qualitative information. For some gear types, the sum of the weight-based and numbers-based columns exceeds the totals column. This indicates that for this gear type a number of records contain both numbers- and weight-based ratios.

Table 2. Total number and number of records in weight-based and numbers-based formats for each gear type in the NRC bycatch database. Source: NRC bycatch database.

Gear Type	Total Number Records	Number Records Weight-based	Number Records Numbers-based
Trawl	966	571	75
Net	232	2	107
Line	150	58	33
Purse seine	82	6	5
Troll	16	0	1
Danish seine	24	21	22
Pot	83	56	41
Other	81	12	0
NS	89	1	1

Each of the major FAO fishing areas is represented within the database. However, bycatch and discard data are best documented for fisheries of the Northeast Pacific and Northeast and Northwest Atlantic, and these areas account for 1,229 of the total database entries. In the Northeast Pacific, extensive observer programs initiated in 1990 have provided comprehensive catch and bycatch data for the groundfisheries of the region. Increasing levels of observer coverage in the crab fisheries of the Northeast Pacific are also contributing new information for this region.

In the Northeast Atlantic, ICES bycatch monitoring programs have provided extensive datasets covering the discards and industrial bycatch of the whiting (*Merlangus merlangus*), hake (*Urophycis tenuis*), haddock (*Melanogrammus aeglefinus*), and plaice (*Pleuronectes platessa*) and other demersal fisheries.

Moreover, the region has been the center of a great deal of bycatch reduction gear experimentation, and a number of papers dealing with technological solutions to discard problems are referenced in the database. Also, the Northwest Atlantic Fisheries Organization (NAFO) has published numerous studies dealing with bycatch in its subject region. In addition, the U.S. National Marine Fisheries Service (NMFS) and Canadian Department of Fisheries and Oceans (DFO) have added substantially to the documentation of bycatch off both coasts of North America.

Other important regional data contributions include FAO Areas 31 (principally the shrimp trawl fisheries of the Gulf of Mexico and U.S. Southeast), 51 and 57 (East and West Indian fisheries), 61 (Japanese and Chinese fisheries and the high seas driftnet fisheries of the region), 71 (fisheries of Southeast Asia, Micronesia, and northeastern Australia), 77 (purse seine tuna and pot lobster fisheries of the ETP), and 81 (line and trawl fisheries of the Southwest Pacific). Only spotty data records were identified for the Mediterranean (Area 37), the Eastern Central Atlantic (Area 34), the Southeast and Southwest Atlantic (Areas 47 and 41), and the Southeast Pacific (Area 87). A map of FAO fishery areas is shown in Figure 2.

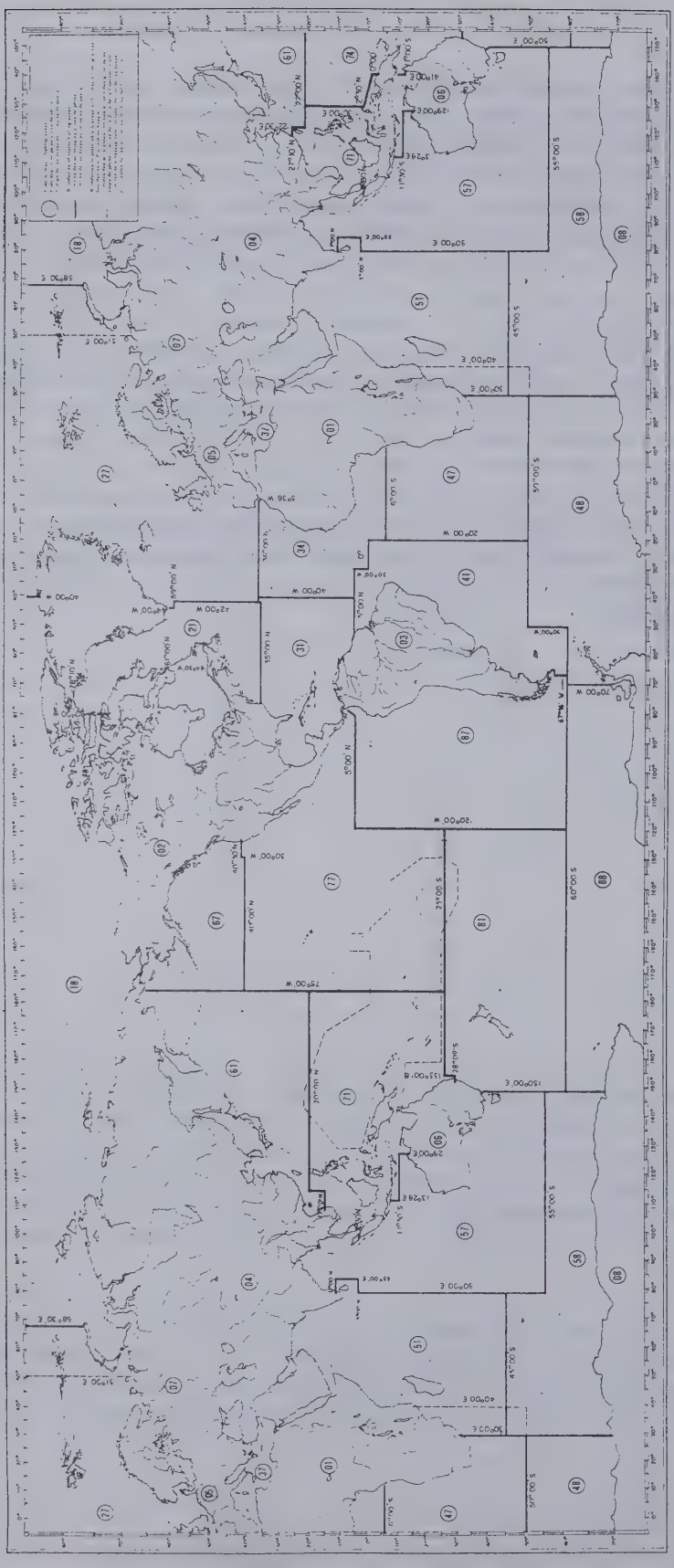

Figure 2. FAO Fishery Statistical Areas. Source: FAO

A total of 55 target species/species groups and 63 bycatch species/species groups is represented within the database. Table 3 documents the number of records associated with the ten most frequently referenced target and bycatch species. Approximately 29% of the database records are associated with target fisheries for shrimp and groundfish species groups. Other groundfish species, such as Alaska pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Atlantic cod (*Gadus morhua*), and whiting, contribute an additional 299 records. Fisheries for squid, *Nephrops*, tuna, and salmon round out the top ten target groups. Together, these ten target species/species groups constitute 1,158 records, two-thirds of all database entries.

Table 3. The number of records associated with the top ten target and bycatch species/groups[3] contained in the NRC bycatch database. Source: NRC bycatch database.

Target Species	Number Records
Shrimp	255
Groundfish	247
Squid	130
Tuna	102
Pacific cod	94
Salmon	71
Atlantic cod	70
Whiting	68
Pollock	67
Nephrops	54

Bycatch Species	Number Records
Salmon	281
Marine mammals	117
Halibut	113
Atlantic cod	63
King crab	48
Haddock	44
Tanner crab	41
Shark	35
Whiting	31
Birds	31

In contrast to the target species breakout, the top ten most referenced bycatch species account for just 47% of all database records. This result should be expected, given that a number of discarded species are often taken in association with a dominant target species. It is also clear bycatch research associated with species having high economic or social value is particularly prevalent in the literature. For example, records pertaining to salmon, halibut, and marine mammals together total almost twice the number of records for all other bycatch species in the top ten list and 30% of all records in the database.

[3] If group species are disaggregated, rankings will change significantly.

Estimates of Global and Regional Bycatch and Discard Levels

The bycatch database offers a means of deriving estimates of a number of parameters regarding areas, species, and populations impacted by bycatch and discards. Although the authors have taken considerable effort to ensure that the global review is exhaustive, it is recognized important literature sources may not have come to our attention and there is a paucity of observations for some regions. Even for those areas where a great number of reported rates are available, the source data may be highly variable. Mangel (1993) discusses in some detail the preference for use of discard data in various forms, including CPUE numbers - and weight-rated based data, and the potential bias of datasets because of time/area variability or the application of certain statistical procedures to species having clustered distribution patterns. In this respect it is important to emphasize discard rates for a particular fishery usually involve a great deal of inter-annual variation, often related to recruitment patterns, changes in regulations, and fishery practices. Because the ratio-based information constituted the only database having adequate regional and global observations, it was chosen as the basis of our estimates. Even this data source does not provide adequate observations for calculation of statistical confidence levels. Thus, all estimates should be seen as provisional in character.

To address situations where discard data associated with a target species are lacking in a region, the authors have applied a set of criteria for selection of surrogate rate data. These bycatch rate selection criteria are:

1. Record must be post-1980
2. If a ratio exists for Target Species A in the region in question, use that ratio
3. If not, use a ratio for Target Species A from a neighboring region
4. Or apply a ratio for Target Species A derived from a global average of ratios associated with that species
5. Or apply a ratio for the species group within which Target Species A resides that is derived from a global average of ratios associated with that species group
6. Derive minimum ratios from summary records (e.g., with bycatch codes 13 and 99)
7. Use minimum-to-maximum range or, when applicable, the global average must include all gear types for which data are available
8. Estimates pertaining to the Bering Sea groundfish fishery are derived from comprehensive NMFS observer sampling data for 1992

In calculating global removals and in developing summary tables of discard ratios by gear or region, the authors have, in a few instances, used their best judgment in the selection of available bycatch data for particular regions or fisheries with which they are especially familiar, such as, the Northeast Pacific or the groundfish fisheries. In some cases, assumptions have been made about average weights of individuals discarded in order to convert numbers-based ratio data into a weight-based form which could contribute to global estimates of discards. These

unit weights can be deduced by viewing formulas in database cells for discard weight corresponding with the subject target species/region combination. In order to improve upon all such estimates and keep the database current, the authors invite on-going discussion of these criteria, judgments, and assumptions from regional fishery experts from around the world. Suggested changes can be readily incorporated into the bycatch database.

Using the above criteria, the authors first analyzed the discard rate data (on a weight basis) considering target species and FAO regions, in order to arrive at an estimate of total global discards. Average annual commercial harvests by species and region for the period 1988 through 1990 were obtained from FAO's computerized landings database, FISHSTAT-PC.[4] These volumes were then applied to the most recent maximum and minimum bycatch ratios recorded in the database for target species in each region. An estimate of discards associated with that target species was obtained by averaging observed maximum and minimum removal values for specific fisheries and regions. This process resulted in a mean estimate of 27.0 million mt of global discards[5], based on a target catch of 77 million mt.[6] Using minimum and maximum observations, we estimate a global discard range of 17.9 to 39.5 million mt.

Not included in these figures are data from freshwater fisheries and marine molluscan fisheries. Aquacultural harvests of shrimp and salmon have also been backed-out of the target harvest baseline. Recreational fisheries discards are also not included in these estimates. While reliable estimates of the weight of global recreational bycatch are lacking, data collected from U.S. fisheries in 1989 document a total discard of 1.035 billion individuals in association with a landed catch of 651.8 million individuals (1.5 individuals discarded to each fish retained). Clearly, recreational fishery discards would add substantially to estimates of global bycatch removals, and a definitive study of their extent is necessary. Further, subsistence fisheries harvest and discard rates were not available.

Our estimate of 27.0 million mt of discards is obviously much larger than Saila's (1983) value of 6.72 million mt. This higher estimate may be indicative of a worsening situation regarding discards, but may also reflect the growth of the available data regarding the scope of the problem. Saila (1983) focused much of his attention on shrimp fisheries. Mean total shrimp bycatch in the present study is

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[4] FISHSTAT-PC is a computer program and database developed by FAO containing historical commercial catch data by region and species.

[5] Includes bycatch landed but unreported by species in industrial fisheries.

[6] Some bycatch observations, particularly for tropical shrimp fisheries, did not provide estimates of the discard portion. Thus, the authors have arrived at discard estimates in these fisheries based on regional comments by numerous authors and inquiries to local fishery managers. Nevertheless, the estimates are at times subjective in nature.

estimated at 11.2 million mt, using more current data.[7] When adjusted for bycatch fractions which are retained, the discards decline to about 9.5 million mt, closer to Saila's estimate from 1983 (Table 4).

Table 4. Estimated bycatch and discards from world shrimp fisheries derived from reported bycatch levels and estimated amount of bycatch retained. Source: NCR bycatch database.

Area	Estimated Bycatch (mt)	Estimated Discard (mt)
Northwest Atlantic	81,665	80,031
Northeast Atlantic	210,297	206,091
West Central Atlantic	1,310,653	1,271,334
East Central Atlantic	123,636	61,818
Mediterranean/Black Sea	257,859	250,124
Southwest Atlantic	253,446	245,842
Southeast Atlantic	39,143	19,571
Western Indian Ocean	1,871,075	748,430
Eastern Indian Ocean	482,879	289,727
Northwest Pacific	4,284,408	4,155,903
Northeast Pacific	28,269	27,421
West Central Pacific	1,450,352	1,377,835
East Central Pacific	590,955	561,416
Southwest Pacific	19,446	18,863
Southeast Pacific	203,677	197,567
Total	11,207,761	9,511,973

Throughout much of North and South America, a very large share of the bycatch taken during shrimp fishing is reported as being discarded. Similar situations are reported in the large Australian northern prawn fishery and in the shrimp fisheries of Europe. For Africa and some areas of Asia, a considerable portion of the bycatch is retained by artisanal fishermen. However, in many other regions the artisanal fisheries have been replaced or supplemented by modern shrimp trawlers and the percentage of bycatch retained has declined. Nevertheless, the trend may be offset by improved markets for species previously discarded in areas of Africa.

[7] Independent estimates of maximum total bycatch in the shrimp fisheries converge at between 16 and 17 million metric tons. Andrew and Pepperell's 1992 estimate of 16.7 million metric tons is only slightly higher than NRC's estimate of maximum shrimp bycatch of 16.4 million metric tons derived in this study.

Regional Break-Outs

Table 5 documents discard weight by major world region. As can be seen, just over one-third of total discards originate in fisheries conducted within the Northwest Pacific. Key contributors to this regional total of 9.1 of million mt are the large crab, true and jack mackerels (*Scomber* spp. and *Trachurus* spp.), Alaska pollock, and cod fisheries of the region, as well as discards associated with the roughly 560,000 mt of wild shrimp harvested in the area.

Table 5. Discard weight by major world region. Source: NRC bycatch database.*

Area	Discard Weight (mt)
Northwest Pacific	9,131,752
Northeast Atlantic	3,671,346
West Central Pacific	2,776,726
Southeast Pacific	2,601,640
West Central Atlantic	1,600,897
West Indian Ocean	1,471,274
Northeast Pacific	924,783
Southwest Atlantic	802,884
East Indian Ocean	802,189
East Central Pacific	767,444
Northwest Atlantic	685,949
East Central Atlantic	594,232
Mediterranean and Black Sea	564,613
Southwest Pacific	293,394
Southeast Atlantic	277,730
Atlantic Antarctic	35,119
Indian Ocean Antarctic	10,018
Pacific Antarctic	109
Total	27,012,099

***Includes bycatch landed but unreported by species in industrial fisheries.**

Discards associated with haddock, whiting, cod, pout (*Trisopterus esmarkii*), plaice, and other flatfish fisheries make a significant contribution to the 3.7 million mt regional bycatch total for the Northeast Atlantic, a total ranking the region as the second largest source of total removals. Capelin (*Mallotus villosus*), with measured discard rates of from 44% to 133%, were also a surprising contributor to aggregate

bycatch in the Northeast Atlantic. Discards in this fishery were attributed primarily to size, quality, and market-condition parameters.

Discards in shrimp fisheries accounted for more than 50% of the total bycatch in West Central Pacific fisheries (Table 4). Shrimp activities off Thailand, Indonesia, and the Philippines produced the bulk of this shrimp fishery discard. Discards associated with harvests of scad, crabs, and tuna also added significantly to the regional total.

The Southeast Pacific ranked fourth among world fishing areas in terms of discards, with 2.6 million mt. Even at very low bycatch rates of 1% to 3%, the large anchoveta and pilchard fisheries in the area produced several hundred thousand tons of discards. Shrimp and mackerel fisheries also added sizable amounts of discard.

Wild shrimp fisheries were responsible for roughly 50% and 80% of regional discard totals in the West Indian Ocean and West Central Atlantic, respectively. In the West Indian Ocean, Indian and Pakistani shrimp fisheries represented the largest sources of discards, whereas in the West Central Atlantic, shrimp fisheries off the southeastern U.S. and in the Gulf of Mexico were responsible for most of the reported bycatch. Crab fisheries also added substantial quantities of discards to the West Central Atlantic total, while various species of carangids and mugilids, considered together, made a sizable contribution to aggregate removals from the West Indian Ocean.

Throughout the temperate and subarctic North Pacific and Atlantic region, discards were generally dominated by sublegal and legal sizes of commercially important cods (*Gadidae*), right-eyed flounders (*Pleuronectidae*), hakes (*Merluccidae*), and rockfishes (*Scorpaenidae*). Exceptions included discards of various species of sharks, eel pouts (*Zoarcidae*), and sculpins (*Cottidae*) and a wide variety of invertebrates. By contrast, in the subtropical and tropical regions of the world, a significant portion of the discards occurring in the shrimp fisheries involved small jacks, pompanos (*Carangidae*), goatfishes (*Mullidae*), lizardfishes (*Synodontidae*), mojarras (*Gerreidae*), threadfins (*Nemipteridae*), tooth ponies (*Leiognathidae*), left-eyed flounders (*Bothidae*), and rays (*Dasayatidae*) (Figure 3). Discards from most tropical shrimp fisheries are mainly comprised of species maturing at sizes under 20 cm and predominantly weighing under 100 grams, or about 1/5 of a pound. However, Conolly (1992) states that off Brazil 50% of the bycatch species are made up of juvenile commercial species.

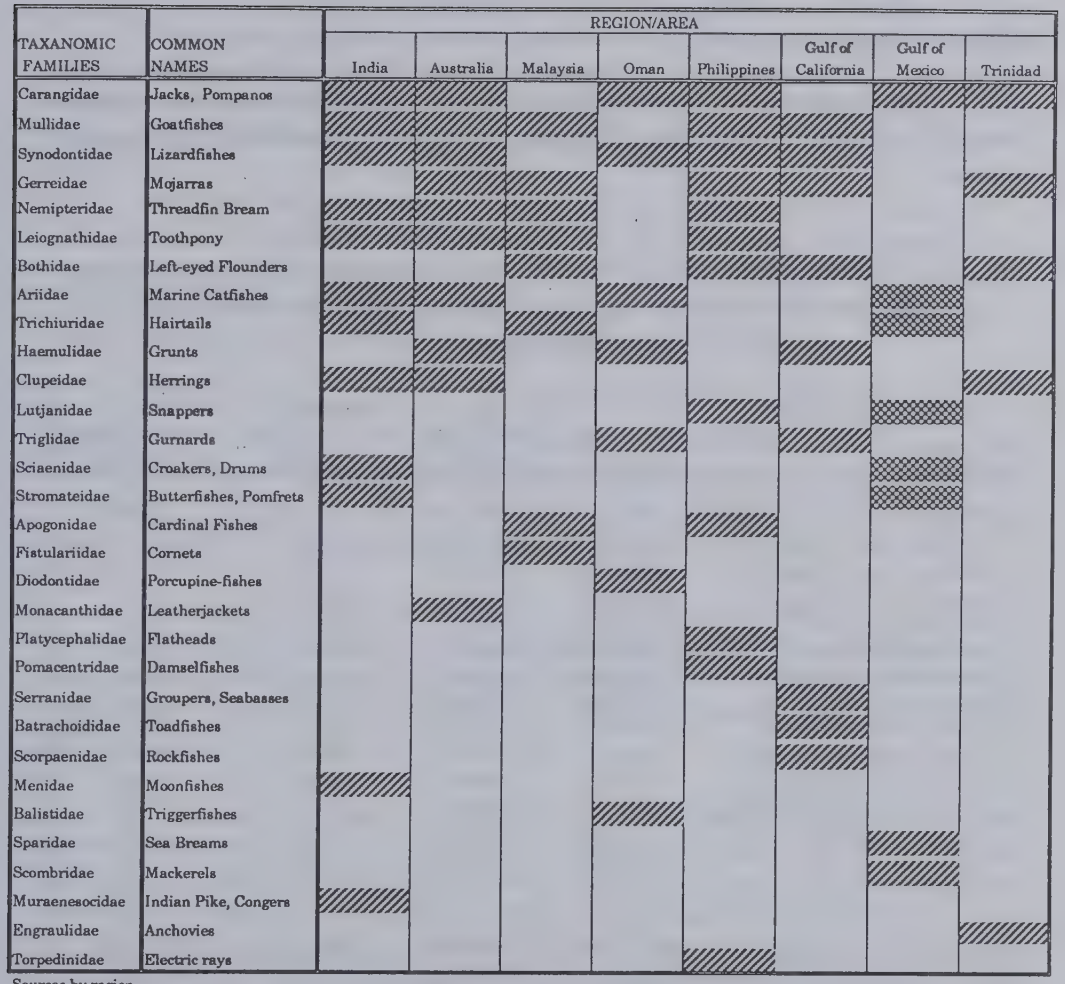

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Figure 3. Major discard families by region. Source: NRC bycatch database.

Species/Group Break-Outs

Table 6 documents global discards on the basis of the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) species groups.

Table 6. Global marine discards on the basis of the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) species groups.*

ISSCAAP	Mean Discard Weight (mt)	Landed Catch Weight (mt)	Ratio of Discarded Weight to Landed Weight	Ratio of Discarded Weight to Total Weight
Shrimps, prawns	9,511,973	1,827,568	5.20	0.84
Redfishes, basses, congers	3,631,057	5,739,743	0.63	0.39
Herrings, sardines, anchovies	2,789,201	23,792,608	0.12	0.10
Crabs	2,777,848	1,117,061	2.49	0.71
Jacks, mullets, sauries	2,607,748	9,349,055	0.28	0.22
Cods, hakes, haddocks	2,539,068	12,808,658	0.20	0.17
Miscellaneous marine fishes	992,356	9,923,560	0.10	0.09
Flounders, halibuts, soles	946,436	1,257,858	0.75	0.43
Tunas, bonitos, billfishes	739,580	4,177,653	0.18	0.15
Squids, cuttlefishes, octopuses	191,801	2,073,523	0.09	0.08
Lobsters, spiny-rock lobsters	113,216	205,851	0.55	0.35
Mackerels, snooks, cutlassfishes	102,377	3,722,818	0.03	0.03
Salmons, trouts, smelt	38,323	766,462	0.05	0.05
Shads	22,755	227,549	0.10	0.09
Eels	8,359	9,975	0.84	0.46
Total	27,012,099	76,999,942	0.35	0.26

*Includes bycatch landed but unreported by species in industrial fisheries.

Immediately apparent from the table, and of little surprise, is the contribution of discards in shrimp fisheries to global removals. Using estimates of mean species discards as the basis for comparison, shrimp fisheries account for about 9.5 million mt of the 27.0 million mt of discards, or 35% of global commercial fisheries discards. Furthermore, out of the 15 ISSCAAP species categories, discards in shrimp fisheries represented more than one-third of the group discard total. In eight of the 18 FAO statistical areas evaluated, shrimp fisheries accounted for more than one-third of the total discards, and in four areas, for more than two-thirds of the discard. Shrimp fisheries, as a gear type, were also characterized by the highest average discard ratios.

The second highest average discard ratio was also associated with a shellfish group--crab. However, the low total harvest of crab drops their global rank in terms of aggregate discard removals to fourth. In the North Pacific crab fisheries, sublegal and immature crab comprise the majority of discards.

The highest discard ratio associated with a finfish species group is tied to flatfishes, although this species group ranks sixth on the list of total removals due to its lower landed total. More than two-thirds of removals of this species groups originate from within the Northeast Atlantic and Northeast Pacific.

Jacks, mullets, and sauries account for 2.6 million mt of bycatch from a landed total of 9.3 million mt. The total is largely a function of documented rates for capelin discards ranging from 44% to 133%. As mentioned already, discards in this fishery were attributed primarily to quality and market-condition parameters. Other species in this group exhibit bycatch rates of less than 5%.

Discards associated with ISSCAAP 32 (cods, hakes, and haddocks) contribute 2.5 million mt of bycatch to the global total. Whiting, cod (Atlantic and Pacific), pout, and Alaska pollock fisheries account for the vast majority of these removals. The large whitefish fisheries of the Northeast Atlantic are alone responsible for 52% of the global total for this species group.

Redfishes and herrings, sardines, and anchovies round out the set of species groups with aggregate bycatch weights in excess of 1 million mt. Despite the very low bycatch ratios associated with the schooling species in ISSCAAP 35, the high annual harvest volumes of this group (23.8 million mt average over the 1988-1990 period) result in substantial discard volumes.

Other species groups of note are the tunas and billfishes with an aggregate bycatch weight of 739,580 mt. This figure may rise, however, if purse seine sets on logs or other fish-aggregating devices (FAD) account for an increasing proportion of total sets in the future. While dolphin removals on log/FAD sets are much lower than when setting on dolphin pods, aggregate removals of other species are much higher. This characteristic will be discussed more fully in an upcoming section covering ecological impacts.

Squid driftnet fisheries have received a great deal of attention in recent years owing to their capture of species having low reproductive rates and relatively long life spans. As documented in Table 6, mean discard weight in all squid fisheries (trawl, jig, and formerly net fisheries) totals approximately 191,801 mt, or 9% of the landed weight, substantially below the global all species rate of 35.1%.

Fishery-Specific Discard Ratios

Tables 7a and 7b identify the twenty fisheries with the highest recorded discard ratios by weight or by numbers. Both formats are presented because in some cases it was impossible accurately to convert rate estimates in one format into values for the other. Consequently, a fisheries presence on one list and absence from the other does not necessarily indicate its rank according to the latter format is

greater than 20 or higher. To avoid such confusion in the future, bycatch researchers should be encouraged to document data in a manner allowing for ready conversion from one measure to the other.

Table 7a. Top twenty fisheries with the highest recorded discard ratios by weight (discard weight per landed target catch weight). Source: NRC bycatch database.

Fishery Description	Kg Discard per Kg Landed
Trinidadian Shrimp Trawl	14.71
Indonesian Shrimp Trawl	12.01
Australian Northern Prawn Trawl	11.10
Sri Lankan Shrimp Trawl	10.96
U.S. Gulf of Mexico Shrimp Trawl	10.30
Sea of Cortes Shrimp Trawl	9.70
Brazilian Shrimp Trawl	9.30
West Indian Shrimp Trawl	8.52
U.S. Southeast Shrimp Trawl	8.00
Northwest Atlantic Fish Trawl	5.28
Persian Gulf Shrimp Trawl	4.17
Southwest Atlantic Shrimp Trawl	4.10
East Indian Shrimp Trawl	3.79
Bering Sea Sablefish Pot	3.51
Malaysian Shrimp Trawl	3.03
Senegalese Shrimp Trawl	2.72
Bering Sea Rock Sole Trawl	2.61
British Columbia Cod Trawl	2.21
Gulf of Alaska Flatfish Trawl	2.08
Northeast Atlantic Dab Trawl	2.01

Table 7b. Top twenty fisheries with the highest recorded discard ratios by number (discard number per landed target catch number). Source: NRC bycatch database.

Fishery Description	Number Discard per Number Landed
West Central Atlantic Shrimp Trawl	12.13
Bering Sea King Crab Pot	9.71
California Halibut Net	4.83
Northeast Atlantic Whiting Trawl	2.83
Bering Sea Tanner Crab Pot	2.34
Northeast Atlantic Haddock Trawl	1.94
Arabian Gulf Finfish Trawl	1.75
Northeast Atlantic Nephrops Trawl	1.70
East Central Pacific Spiny Lobster Pot	1.68
East Central Pacific Swordfish Longline	1.58
Northeast Atlantic Hake Trawl	1.18
East Indian Ocean Tuna Longline	1.13
Northeast Atlantic Cod Danish Seine	0.79
Northeast Atlantic Haddock Danish Seine	0.70
East Central Pacific Slipper Lobster Pot	0.67
Northeast Atlantic Whiting Danish Seine	0.64
Northeast Atlantic Cod Trawl	0.51
Northeast Atlantic Plaice Trawl	0.42
Carribbean Tuna Longline	0.40
Japanes High Seas Squid Net	0.39

Shellfish fisheries (shrimp, crab, *Nephrops*) as a whole comprise 14 of the top 20 weight-based discard ratios and 20 of the top 40 ratios when looking across both classifications. Shrimp fisheries, of course, predominate, with shrimp trawl ratios accounting for the top nine weight-based ratios and the highest numbers-based estimate. Only six finfish fisheries occur on the list of highest weight-based discard ratios.

In terms of gear type, trawl fisheries dominate the weight-based breakout (19 of the top 20). The top discard ratios are more evenly distributed across gear types in the numbers-based list. Line and net fisheries, absent from the top 20 weight-based list, contribute five ratios to the top 20 numbers-based set. Four pot fisheries and three Danish seines are also a part of the numbers-based breakout.

Trawl fisheries, however, are also well represented on lists of the ten lowest weight-based and numbers-based discard ratios (Tables 8a and 8b). Eight of the ten lowest weight-based records are associated with trawl fisheries. One pot fishery for Pacific cod and an Atlantic menhaden (*Brevootia tyrannsus*) seine fishery round out

the bottom ten list. In terms of numbers, driftnet fisheries for tuna and squid constitute five of the ten lowest ratios and are joined by two midwater Alaska pollock fisheries, one Pacific cod pot fishery, and one ETP tuna purse seine fishery.

Table 8a. The ten lowest observed weight-based discard ratios in fisheries other than shrimp (discard weight per landed target catch weight). Source: NRC bycatch database.

Fishery Description	Kg Discard per Kg Landed
Northwest Atlantic Hake Trawl	0.011
West Central Atlantic Menhaden Seine	0.029
Bering Sea Cod Pot	0.041
Northeast Pacific Whiting Trawl	0.043
Northwest Atlantic Cod Trawl	0.058
Bering Sea Pelagic Pollock Trawl*	0.062
Northwest Atlantic Redfish Trawl	0.063
Northeast Atlantic Groundfish Trawl	0.083
Gulf of Alaska Midwater Pollock Trawl	0.086
Northwest Atlantic Plaice Trawl	0.118

*Includes some on-bottom fishing.

Table 8b. The ten lowest observed numbers-based discard ratios in fisheries other than shrimp (discard number per landed target catch weight). Source: NRC bycatch database.

Fishery Description	Number Discarded per Number Landed
Bering Sea Midwater Trawl Pollock	0.005
Northeast Atlantic Tuna Driftnet	0.009
Gulf of Alaska Midwater Trawl Pollock	0.018
(Korea) Northwest Pacific Squid Driftnet	0.037
(Taiwan) Northwest Pacific Squid Driftnet	0.068
Sub-Tropical Convergence Zone Tuna Driftnet	0.08
Tasman Sea Tuna Driftnet	0.123
Bering Sea King Crab Pot	0.132
Eastern Tropical Pacific Tuna Purse Seine	0.18
Bering Sea Cod Pot	0.18

Gear-Specific Discard Rates

Tables 9a and 9b take a closer look at weight-based and numbers-based bycatch ratios, respectively, from a gear-specific perspective. Although differences in discard ratios can be observed between gear types, four major ratios groups can be identified. Shrimp trawls stand alone at the top of the list of high discard ratios, while relatively low ratios are reflected for pelagic trawls, purse seines targeting on menhaden, sardines, and anchoveta, and some of the high seas driftnet fisheries. Between these high and low values lie two groups. The first of these is comprised of bottom trawls, unspecified (probably near-bottom) trawls, longline gear, and the majority of the pot fisheries. The remaining group falls in between the very low ratios of the midwater trawl group and the moderate ratios of the aforementioned bottom trawl/line/pot group. This last set of gear types includes the Japanese high seas driftnet fisheries, Danish seines, and purse seines for capelin.

The highest discard ratios by region, across gear type, are presented in Table 10. In the Northwest Atlantic, rates are led by the 1.58 kg discard per kg of target landings in the New England yellowtail flounder trawl fishery, while a dab trawl rate of 2.01 kg discard/kg target is at the top of the Northeast Atlantic list. Three gear types are represented in the top five list for the Mediterranean/Black Sea region, while shrimp trawls alone comprise the set of five highest records for the West Central Atlantic and West Central Pacific. In the Northeast Pacific, the region containing perhaps the most comprehensive discard database, the top five rates range from 3.51 kg discard/kg target in the Bering Sea sablefish pot fishery to 2.08 kg discard/kg target in the Gulf of Alaska flatfish trawl fishery. Regions for which data gaps preclude a full set of records are the West Central, East Central, and Southwest Atlantic, the Eastern Indian Ocean, the Eastern Central Pacific, and the Southwest Pacific.

Table 9a. The top weight-based discard to landed target catch ratios by gear type. Source: NRC bycatch database.

Fishery Description		Kg Bycatch per Kg Landed
Non-Pelagic Fish Trawl		
	Northwest Atlantic Fish Trawl	5.28
	Bering Sea Rock Sole	2.61
	British Columbia Pacific Cod	2.21
	Gulf of Alaska Flatfish	2.08
	Northeast Atlantic Dab	2.01
Pelagic Fish Trawl		
	Bering Sea Pollock-1988	0.01
	Northeast Atlantic Cod	0.00
	Bering Sea Pollock-1989	0.00
	Gulf of Alaska Pollock-1989	0.00
	Bering Sea Pollock-1987	0.00
Shrimp Trawl		
	Trinidad	14.71
	Indonesia	12.01
	Australia	11.10
	Sri Lanka	10.96
	U.S. Gulf of Mexico	10.30
Longline		
	Eastern Central Pacific Swordfish-1990	1.13
	Bering Sea Greenland Turbot	1.03
	Eastern Central Pacific Swordfish-1991	1.00
	Bering Sea Sablefish	0.50
	Gulf of Alaska Cod	0.26
Purse Seine		
	Northwest Atlantic Capelin-1983	0.81
	Northwest Atlantic Capelin-1981	0.37
	East Central Atlantic Sardine	0.03
	U.S. Gulf of Mexico Menhaden	0.03
	West Central Pacific Tuna	0.00
Danish Seine		
	Northeast Atlantic Haddock	0.50
	Northeast Atlantic Whiting	0.45
	Northeast Atlantic Cod	0.36
Pot/Trap		
	Bering Sea Sablefish	3.51
	Bering Sea King Crab	3.39
	Bering Sea Tanner Crab	1.78
	Northwest Atlantic Capelin	0.80
	East Central Pacific Spiny Lobster	0.36

Table 9b. The top numbers-based discard to landed target catch ratios by gear type. Source NRC bycatch database.

	Fishery Description	Bycatch Number per Target Number
Trawl		
	Caribbean Shrimp	12.13
	Northeast Atlantic Whiting	2.83
	Northeast Atlantic Haddock	1.94
	Arabian Gulf Finfish Trawl	1.75
	Northeast Atlantic Nephrops	1.70
High Seas Driftnet		
	Japanese North Pacific Squid	0.37
	Japanese Tasman Sea Tuna	0.12
	Japanese Sub-Trop Convergence Zone Tuna	0.08
	Taiwan North Pacific Squid	0.07
	Korean North Pacific Squid	0.06
Longline		
	Eastern Central Pacific Swordfish	1.58
	Eastern Indian Ocean Tuna	1.13
Danish Seine		
	Northeast Atlantic Cod	0.79
	Northeast Atlantic Haddock	0.70
	Northeast Atlantic Whiting	0.64
Pot/Trap		
	Bering Sea King Crab	9.71
	Bering Sea Tanner Crab	2.35
	Eastern Central Pacific Spiny Lobster	1.68
	Eastern Central Pacific Slipper Lobster	0.67
	American Lobster	0.22

Table 10. The highest discard to target catch ratios by region (discard weight per landed target catch weight). Source: NRC bycatch database.

Fishery Description	Kg Bycatch per Kg Landed
Northwest Atlantic	
New England Yellowtail Flounder Trawl	1.58
Newfoundland Shrimp Trawl	1.38
Atlantic Canada Capelin Seine	1.33
Atlantic Canada Groundfish Trawl	0.80
Atlantic Canada Capelin Trap	0.80
Northeast Atlantic	
Baltic Sea Dab Trawl	2.01
Irish Sea Nephrops Trawl	1.95
Baltic Sea Flounder Trawl	1.60
North Sea Shrimp Trawl	1.44
North Sea Whiting Trawl	1.34
West Central Atlantic	
Trinidad Shrimp Trawl	14.71
US Gulf of Mexico Shrimp Trawl	10.30
US Southeast Shrimp Trawl	8.00
East Central Atlantic	
Shrimp Trawl off Senegal	2.72
Finfish Trawl off Senegal	1.48
Mediterranean and Black Seas	
Finfish Trawl	0.85
Tuna Longline	0.10
Hake Trawl	0.04
Sardine Purse Seine	0.03
Flatfish Trawl	0.03
Southwest Atlantic	
Brazilian Shrimp Trawl	4.10

Table 10 (continued).

Fishery Description	Kg Bycatch per Kg Landed
West Indian Ocean	
Sri Lankan Shrimp Trawl	10.96
West Coast Indian Shrimp Trawl	8.52
Persian Gulf Shrimp Trawl	4.17
Arabian Gulf Finfish Trawl	0.64
East Indian Ocean	
East Coast Indian Shrimp Trawl	3.79
Northeast Pacific	
Bering Sea Sablefish Pot	3.51
Bering Sea King Crab Trawl	3.39
Bering Sea Rock Sole Trawl	2.61
British Columbia Cod Trawl	2.21
Gulf of Alaska Flatfish Trawl	2.08
West Central Pacific	
Indonesian Shrimp Tral	12.01
Australian Northern Prawn Trawl	11.10
Malaysian Shrimp Trawl	3.03
Malaysian Finfish Trawl	0.44
Thailand Finfish Trawl	0.15
East Central Pacific	
Mexican Shrimp Trawl	9.70
Hawaiian Swordfish Longline	1.12
Hawaiian Spiny Lobster Pot	0.36
Hawaiian Slipper Lobster Pot	0.17
Southwest Pacific	
Hoki Trawl	0.30

Bycatch of Marine Mammals

Our quantitative assessment of weight- and numbers-based bycatch and discard levels in world fisheries considers only levels and ratios for finfish and some invertebrate populations. Nevertheless, many of the oceans' living resource management conflicts surfacing in recent years have been concerned with marine mammals, turtles, or birds. In the past decade it has been well documented that the capture of marine mammals and other marine life in fishing gear can be a serious problem in terms of impacts imposed on marine mammal populations and public ethical concerns. (Northridge 1991a, 1991b, 1991c; Nelson and Lien 1992; IWC Workshop Report 1991; F. Alverson, in press; DeGange and Day 1991; Perrin 1988; Jones 1988; Dawson 1991a, 1991b; Snow et al. 1987; Brownell et al. 1989; Oshumi 1972; Manning 1989; Polacheck 1989; Barlow et al. 1990; Mohan 1985;

Reynolds 1985; Perkins et al. 1990-1991, 1992; Read and Gaskin 1988; Lien et al. 1987; Mate 1980; and many others).

Although it is known by marine scientists, conservation groups, and the general public that a wide variety of interactions occur between marine mammals and fisheries (Northridge, 1991b), the quantities of discards involved are generally less well known and more speculative than those for many commercially harvested fish or shellfish.

Northridge (1991b) notes "most marine mammals, with the exception of the rarer ocean beaked whales, for example, have been recorded at some time or other caught in some type of fishing gear." In a detailed examination of mortalities of cetaceans in passive fishing gears during the IWC Workshop held at La Jolla, California, in 1990, scientists were able to identify 54 species/populations/regions (SPRs) for which abundance estimates and data on incidental mortality in passive gears were available. Rough estimates were made for many other species/populations/areas (see IWC Workshop 1990, Table 1). This listing of species involves only cetaceans interacting with passive gear and does not include species of bycatch taken by active fishing gears or species from other taxonomic groups, such as seals, sea lions, manatees, and dugongs.

The IWC reports make it apparent that considerable qualitative data are available concerning observed bycatch of marine mammals in a variety of fisheries. However, few references provide specific bycatch ratios, and for most fisheries only a small portion of marine mammal catch is recorded (Northridge 1991b). Thus, it is much more difficult to assess global harvest and impacts of the marine mammal discards than for fisheries. Nevertheless, data provided by Northridge (1991a, 1991b) and the IWC Workshop (1991) provide an indication of the potential magnitude of such takes.

The IWC Workshop data can account for potential marine mammal discard mortalities ranging from 65,000 to 86,000 animals annually. These figures are based on summing the range of estimates of mortalities regardless of years, and it is questionable whether higher estimates of mortalities occurred simultaneously in any one year. On the other hand, it must be noted that the IWC scientists, because of inadequate data, could not provide any information on seven SPRs, could do no better than report "some" as the mortality level for 86, and for many other SPRs noted reported mortalities as being less than or greater than some specific number. Thus, the estimate for mortalities associated with passive gears needs to be considered as conservative (Northridge 1991b). The actual catch must be considerably greater.

Cetacean species and areas for which relatively large numbers of bycatch have been observed include Dall's porpoise (*Phocoenoides dalli*) in the Western and Central North Pacific, Risso's (*Grampus griseus*) and spinner dolphins (*Stenella longirostris*) off Sri Lanka, harbor porpoise (*Phocoena phocoena*) off

Eastern Canada, common dolphin (*Delphinus delphis*) in the Southwest Indian Basin and Tasman Sea, Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) off coastal Japan, dusty dolphin (*Lagenorhynchus obscurus*) off Peru, northern right dolphin (*Lissodelphis borealis*) in the Central Pacific, pan-tropical spotted dolphin (*Stenella attenuata*) in the North Indian Ocean, striped dolphin (*Stenella coeruleoalba*) in the Mediterranean, spinner and bottlenose dolphin (*Tursiops truncatus*) off Australia, and spotted, spinner, and common dolphin in the ETP (Northridge 1991b).

In addition to the cetacean discard estimates provided by the IWC for passive gears, a considerable incidental catch is reported for various active fishing gears. Northridge (1991b) and the National Research Council (1992) indicate bycatch dolphin mortality in the ETP tuna purse seine fishery may have approached 100,000 animals in 1989, a decline from an estimate of about 140,000 animals in 1986, and perhaps much larger numbers in the 1960s. Discard mortalities in the ETP tuna purse seine fishery have continued to decline since 1989 (National Research Council 1992) (Figure 4). Nevertheless, from the ecological viewpoint, the gains made with the decline in dolphin mortality have been offset by a substantial increase in the discards of young tuna and other pelagic fish species (Table 11). Documented dolphin mortalities in the ETP tuna purse seine fishery involve a single fishery, and F. Alverson (in press) notes some dolphins are taken in association with almost all world seine fisheries. Further, it is well known that seals, sea lions, and other marine mammals are incidentally taken in many of the world's fisheries. Examples of discard mortality as a function of fishery production (i.e., target catch) for purse seining and gillnets by areas are provided in Table 12.

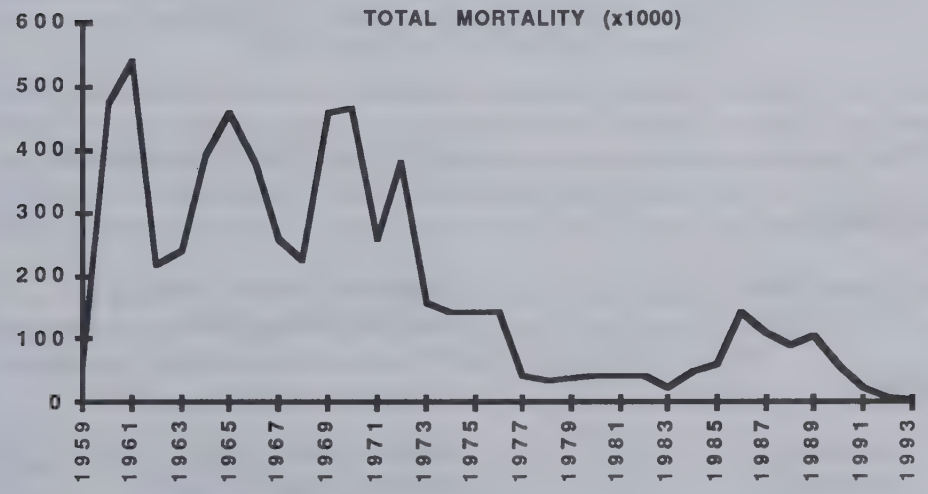

Figure 4. Discard mortalities (numbers of porpoise) in the Eastern Tropical Pacific tuna purse seine fisheries, 1959-1993. Source: Hall/IATTC per. comm. 1993.

Table 11. Discards of young tuna and other pelagic fish species in the ETP tuna fishery (number of fish). Source: Hall/IATTC per. comm. 1993.

Species	School Sets (n = 1,060)	Log Sets* (n = 324)	Dolphin Sets (n = 764)
Dolphins	8	31	4,500
Small tunas	5,230,000	128,700,000	833,000
Mahi mahi	1,811	402,577	628
Sharks	17,632	133,920	5,104
Wahoo	208	52,469	13
Rainbow runners	255	42,068	
Other small fish	1,708	10,123	523
Billfish	2,349	9,105	759
Yellowtail	47	5,895	39
Sea turtles	471	617	143
Other large fish	1,151	8,611	
Trigger fish	283	34,938	
Sample size	1,060	324	764

*Estimates in this column are likely to be overestimates because more fishing on existing objects or addition of objects will not result in linear increases of the catches.

Table 12. Dolphin mortality and fishery production. Source: Hall/IATTC pers. comm. 1993.

Gear Type	Dolphin Mortality/Fishery Production
Purse Seining	
Eastern Pacific	1 dolphin/40-50 tons of tuna
Philippines	1 dolphin/2.2 tons of tuna
Gillnets	
Ivory Coast	1 dolphin/2.2 tons of tuna
Sri Lanka	1 dolphin/4.4 tons of "fish"
Bay of Biscay	1 dolphin/2.7 tons of albacore
Gulf of Maine	1 dolphin/10 tons of demersal fish

Information about the quantities of seals, sea lions, and other marine mammals taken incidentally in fishing gear is even less quantifiable than for cetaceans. Northridge (1991b), in his review of interactions between marine mammals and fisheries, lists numerous species for which documented bycatches have been observed. Significant interactions are noted between fisheries and the northern sea lion (*Eumetopias jubatus*) northern fur seal (*Callorhinus ursinus*), harp seal (*Phoca groenlandica*), gray seal (*Halichoerus grypus*), Caribbean manatee (*Trichechus manatus*), Mediterranean monk seal (*Monachus monachus*), franciscana (*Pontopocia blainvillei)*, dugong (*Dugong dugon*), harbor seal (*Phoca vitulina*), and New Zealand fur seal (*Arctocephalus forsteri*). Perez and Loughlin (1991) also provide an excellent review of the numbers of incidental catches of marine mammals taken in North Pacific trawl fisheries, an area where thousands of animals were taken yearly during the 1970s and 1980s.

Because of the lack of discard rate data for marine mammals, we, like others, are hesitant to estimate a total number and weight of discards for marine mammals. It seems conservative to conclude that several hundreds of thousands of animals are involved annually. However, technological developments in the ETP region, the disappearance of several major high seas driftnet fisheries, national regulations controlling marine mammal bycatch, and fishermen's education programs supervised by scientists may have helped to reduce the total levels of marine mammal mortalities in recent years.

It would appear marine mammal bycatch occurs in almost all major gear types, including driftnets/gillnets, bottom trawls, pots, longlines, tangle/trammel nets, fish traps, purse seine and other round nets, pelagic trawls, setnets, etc. The largest numbers of marine mammal bycatch appear to occur incidentally or as the result of sets on porpoises in various driftnets/gillnets and tuna seine fisheries (Northridge, 1991b; National Research Council 1992).

Sea turtle takes have also been reported in ocean longline operations. Annual incidental takes have been reported at 40,000 worldwide and 21,200 in the Western Pacific and South China Sea alone. Mortality rates have been estimated at 42% for turtles incidentally taken by longline gear (Nishemura and Nakahigashi 1990). Some scientists feel this estimate is too low (Paul Dayton, personal comm.).

Because of the lack of broad-scale quantitative data on birds, we have not attempted to establish regional or global losses of these species groups. However, comments on impacts on birds are provided in the following chapter.

Discard Mortality Rates

Biological and ecological impacts, as well as other impacts resulting from discards, will vary between species depending on (1) the quantities taken, (2) the survival rates of discarded species, and (3) the population characteristics and life

histories of impacted species. During the review of the bycatch and discard literature, it became evident that over the past decade considerable energy has been expended to compile and improve discard information. On the other hand, relatively little effort seems to have been made to research and chronicle the mortality rates associated with discards. Of course, the ultimate consequence of discarding depends on the mortalities imposed on the relevant populations. Nevertheless, recorded mortality rates documented in studies reviewed are presented. The most complete report identified by the authors on discard mortalities for the Northeast Pacific is entitled "The Nature and Scope of Fishery Dependent Mortalities in the Commercial Fisheries of the Northeast Pacific" (NRC 1990). This report contains information on available mortality data for halibut, crab, and salmon. Information from this paper is summarized below.

Halibut

Halibut discard mortality estimates are highly variable (Table 13). Values range from a low of 2% reported in the North Pacific foreign longline fisheries to a high of 100% in several trawl and pot fisheries. Thirty-one percent to 100% of all halibut incidentally taken in crab pots are expected to die. Halibut taken by small and large foreign trawlers in the Bering Sea/Aleutian Islands in the 1970s and 1980s were reported to have experienced slightly higher mortality rates (25% to 54%) than those incidentally taken by similar operations conducted in the Gulf of Alaska (9% to 31%). Other reports of halibut mortality in foreign trawl fisheries in the North Pacific reach as high as 100%. Ninety percent of the halibut taken by joint venture trawlers in the Bering Sea/Aleutian Islands were judged as dead, while only 60% were so described in observed Gulf of Alaska joint venture trawl operations.[8] Bycatch mortality of U.S. and Canadian trawl-caught halibut ranges from 10% to 72%. In a study using tag returns (Williams et al. 1989; Hoag 1971, 1975) to estimate mortality, smaller, sublegal halibut (<80 cm) suffered a substantially higher mortality rate (72%) in the domestic trawl fishery off British Columbia than did larger (>80 cm) halibut (45%). As much as 50% to 100% of all halibut caught in shrimp trawls die.

Discard mortalities within foreign longline fisheries have been estimated to range from 2% to 50%. Halibut taken by domestic longliners experienced a minimum bycatch mortality of 32% and a maximum of 50%. Forty percent of the halibut taken in the Pacific cod longline fishery were judged as dead or in poor condition. Sublegal halibut caught incidentally within the U.S. longline fishery for halibut experienced a mortality range of 25% to 40%. Over the past several years, scientists working with the North Pacific Fishery Management Council have evaluated observer data and attempted to provide their best estimates of halibut mortality rates imposed by the various North Pacific demersal fisheries. The mortality rates used in 1992 and recommended for 1994 for the Gulf of Alaska and the Bering Sea are somewhat lower than for earlier observations (Table 14).

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[8] Catches by U.S. vessels were subsequently offloaded onto foreign vessels for processing.

Table 13. Halibut discard mortality rates estimated by fishery. Source: NRC 1990.

Bycatch Species	Area	Fishery	Mortality Percentage
Halibut	BS/AI	Trawl, JV	90
Halibut	BS/AI	Trawl, large	25-54
Halibut	BS/AI	Trawl, mothership/freezer	90
Halibut	BS/AI	Trawl, small	25-54
Halibut	GOA	Crab Pot, Tanner	45
Halibut	GOA	Crab Pot, Tanner	31
Halibut	GOA	Groundfish trawl	36
Halibut	GOA	Trawl, JV	60
Halibut	GOA	Trawl, large	9-31
Halibut	GOA	Trawl, small	9-31
Halibut	North Pacific	Crab pot, domestic	45-100
Halibut	North Pacific	Japanese groundfish trawl	90-100
Halibut	North Pacific	Longline	25
Halibut	North Pacific	Longline, domestic	32-50
Halibut	North Pacific	Longline, domestic	32-50
Halibut	North Pacific	Longline, foreign	10-50
Halibut	North Pacific	Longline, foreign	2-14
Halibut	North Pacific	Longline, foreign	10-50
Halibut	North Pacific	Shrimp	100
Halibut	North Pacific	Shrimp trawl, domestic	50
Halibut	North Pacific	Trawl, domestic	10-42
Halibut	North Pacific	Trawl, foreign	50-100
Halibut	Washington	Setnet	36-69
Halibut <80 cm	British Columbia	Trawl, domestic	72
Halibut <80 cm	British Columbia	Trawl, domestic	45
Sublegal halibut	GOA	Longline, domestic halibut	33-40
Sublegal halibut	BS/AI and GOA	Longline, domestic halibut	25

Table 14. Trend in halibut discard mortality rates during 1990 through 1993 and recommendations for 1994 preseason rates. Change are noted with an asterisk (*). Source: NPFMC SAFE Document, 1994.

Region/Target	1990	1991	1992	1990-92 Average	Prelim 1993	Used In 1993	1994 Recommendation
BS/AI TRAWL							
MWT Pollock	81	81	87	83	86	80	80
Atka mackerel	69	73	62	68	69	70	70
Rock sole/Oflats **	58	68	78	68	74	70	70
Yellowfin sole **	73	74	77	75	81	70	75*
Pacific cod	68	60	67	65	65	60	65*
BT pollock	65	59	76	67	87	60	65*
Rockfish	62	54	59	58	75	60	60
Arrowtooth	57	41		49		40	50*
Grnld. turbot	58	38		48		40	45*
Other sp.	36	29		33	72	40	40
GOA TRAWL							
MWT Pollock	63	74	69	69	61	75	70*
Rockfish	61	65	69	65	59	60	65*
BT Pollock	65	56	70	64	43	55	65*
Shallwtr. flatfish	62	61	62	62	63	60	60
Other sp.	63	59	64	62	55	60	60
Pacific cod	61	55	59	58	58	55	55
Deepwtr. flatfish	57	52	59	56	58	55	55
BS/AI H&L	17	21	18	19	17	18	15*
Pacific cod	13	18	19	17	18	12.5/15	15*
Sablefish	18	29		24		12.5/15	15*
Rockfish			17	17	8	12.5/15	15*
Grnld. turbot							
GOA H&L							
Pacific cod	13	17	30	20	8	16	15*
Sablefish	11	28	23	21	19	14/17	15*
Rockfish	15	20		18		11.5/14	15*
BS/AI POT							
Pacific cod	7	3	12	7	4	5	5
GOA POT							
Pacific cod	10	5	16	10	22	5	10*

** During 1990 and 1991, "Other flatfish" was grouped with yellowfin sole. Since 1992, the target has been grouped with rock sole.

Nielson et al. (1989), in a field experiment on the viability of Atlantic halibut taken by trawls and longline, report 35% of the trawl-caught halibut and 75% of the longline-caught halibut below a proposed size limit survive for 48 hours after capture.

Crab

Like those for halibut, reports of king crab discard mortalities are extremely variable (Table 15). Mortality estimates for trawl-caught king crab (*Paralithodes* spp.) range from 2% to 81%. Tanner crab (*Chionoecetes* spp.) mortality estimates are no less unpredictable, and values of as low as 12% and as high as 82% have been reported. In a study investigating king and Tanner crab taken by trawlers off Kodiak (Blackburn and Schmidt 1988), only 2% of the king and 36% of the Tanner crab were judged injured or dead. Dead king crab were much more common during the February through June period (19%) than in the remainder of the year (0.9%). In a separate study (Stevens 1989), king and Tanner crab were held in live-tanks for up to 17 hours after capture by Bering Sea/Aleutian Islands joint venture sole trawlers. Mortalities of 77% to 81% for king crab and 74% to 82% for Tanner crab were observed. Suffocation, not noticeable external injuries, was found to contribute most substantially to the recorded mortalities. Crab mortality studies which did not distinguish between the types of crab taken in the trawl reported mortality rates of 50% to 100%. Finally, 0% to 50% of all crab taken with longline fisheries are expected to die.

Dungeness crab (*Cancer magister*) mortality estimates are surprisingly low. In trawls, hardshell and softshell Dungeness mortality has been estimated at 2% and 9%, respectively. Female Dungeness crab suffer a slightly higher trawl bycatch mortality (6% to 11%) than do males (0% to 4%). Softshell mortality within the Dungeness crab pot fishery has been reported at 22% to 25%. Mortality of sublegal hardshell Dungeness crab within the Dungeness fishery is much lower (2% to 4%).

Table 15. Reported crab bycatch mortality rates in North Pacific fisheries. Source: NRC 1990.

Bycatch Species	Area	Fishery	Mortality Percentage
Crab	GOA	Longline	50
Crab	GOA	Trawl	100
Crab	North Pacific	Longline, domestic halibut	50
Crab	North Pacific	Trawl	50-100
Dungeness crab (hardshell)	Washington	Trawl	2
Dungeness crab (hardshell)	West Coast	Crab pot, dungeness	2-4
Dungeness crab (softshell)	Washington	Trawl	9
Dungeness crab (softshell)	West Coast	Crab pot, dungeness	22-25
Dungeness crab, females	GOA	Trawl	6-11
Dungeness crab, males	GOA	Trawl	0-4
King crab	BS/AI	Trawl, JV sole	77-81
King crab	GOA	Trawl	2
King crab	North Pacific	Trawl	19
King crab	North Pacific	Trawl	79
Softshell king crab	GOA	Trawl	21
Tanner crab	BS/AI	Trawl, JV sole	74-82
Tanner crab	GOA	Trawl	36
Tanner crab	North Pacific	Trawl	12
Tanner crab	North Pacific	Trawl	78

Salmon

Salmon mortality rates range from a low of 8% for legal-sized chinook (*Oncorhynchus tshawytscha*) taken in troll fisheries for other salmon in Southeast Alaska to a high of 100% for salmon taken in longline operations in the North Pacific (Table 16). However, the latter fishery takes only a small amount of the salmon taken by the regional bottom fisheries. Most are taken in trawls and are presumed to be dead. Legal-sized chinook losses in troll fisheries for other salmon are only slightly lower (8% to 25%) than mortalities associated with sublegal-sized chinook (19% to 28%). Illegal troll-caught coho (*Oncorhynchus kisutch*) are reported to suffer a much higher rate of mortality (34% to 52%) than illegal chinook. As would be expected, barbed hooks raise this mortality substantially. Seventy-seven percent of the juvenile coho caught on barbed hooks died, compared to only a 33% rate of

mortality when caught on barbless hooks. Recent work has demonstrated that mortality rates range from 6% to 11% of coho and chinook, respectively, hooked and released by recreational anglers (NRC 1993).

Table 16. Reported salmon mortality rates in North Pacific fisheries. Source: NRC 1990.

Bycatch Species	Area	Fishery	Mortality Percentage
Chinook	North Pacific	Purse seine	50-90
Chinook	North Pacific	Troll	20-30
Chinook	Washington	Gillnet	2-28
Chinook, large	SE Alaska	Purse seine	24
Chinook, medium	SE Alaska	Purse seine	68
Chinook, small	SE Alaska	Purse seine	60
Chinook, illegal	SE Alaska	Purse seine	50-90
Chinook, legal	GOA	Troll	25
Chinook, legal	GOA	Troll, coho	20
Chinook, legal	SE Alaska	Troll	8-13
Chinook, sublegal	GOA	Troll	28
Chinook, sublegal	GOA	Troll, coho	24
Chinook, sublegal	SE Alaska	Troll	19-28
Coho, illegal	West Coast	Troll	34-52
Coho, illegal	West Coast	Troll	42
Coho, juvenile	West Coast	Troll (barbless hooks)	77
Coho, juvenile	West Coast	Troll (barbed hooks)	33
Salmon	North Pacific	Longline	100

Reported purse seine chinook mortalities have generally been significantly higher than troll mortalities. Up to 50% to 90% of all legal- and illegal-sized chinook caught by purse seiners die. In a study in which purse seine mortality was separated by size (Rowse and Marshall 1988), 68% of all medium-sized (21" to 28") and 60% of all small-sized (<21") chinook caught by purse seiners died. Only 24% of the large (>28") chinook taken as bycatch died.

Chinook dropout losses in Puget Sound gillnet fisheries have been estimated at 2% to 3%. Predation losses accounted for an additional 2% to 9% of observed mortalities, but reached as high as 28% in areas of high seal populations.

A report of the NOAA/NMFS (1990/1991) on recreational fisheries note about 50.5% of the total marine recreational catch was released alive, but it is not

apparent what percentage of the total catch was discarded dead. Estimates of "released alive" come from the fishermen and the ultimate amount of discards is unknown. Recent studies, however, by NRC (1993) indicate a relatively high rate of survival for chinook and silver salmon (*Oncorhynchus kisutch*) taken in recreational fisheries, approximating 90%.

Other Observations Regarding Discard Mortality

Many researchers believe survival rates for fishes, particularly those species left floating on the sea's surface, are low (Wassenberg and Hill 1990). For cods, whiting, and rockfishes (*Sebastes*) whose air bladders expand and trap them at the surface, survival rates are expected to be very low. Cushing (1984) assumed that of the estimated 40 million whiting discarded each year, all die. Similarly, for many tropical species of the snapper and grouper families, survival rates must also be low (Seidel 1975; Caddy 1982; Howell and Langan 1987). Hill and Wassenberg (1990) examined the fate of discards from prawn trawlers in Torres Strait, Australia, and noted about half of the discarded fish and 25% of the cephalopods floated, but none of the non-commercial crustaceans floated. The percentage of each group examined that survived ranged from 2% for finfish and cephalopods up to 51% for crustaceans. Results of their work for fish subjected to 10-30 minute exposures on deck and subsequently discarded (into holding tanks) are shown in Tables 17a and 17b. Factors contributing to mortality of discards include (a) the character of the gear deployed, (b) sorting methods and duration of sorting time, (c) fishing time, (d) size of catch for trawls and seines, (e) associated species in the catch, and (f) environmental conditions (Wassenberg and Hill 1989; Nielson et al. 1989; Van Beek et al. 1990).

Table 17a. Percentage (by weight) of three taxonomic groups in a subset of discards (fish, non-commercial crustaceans, and cephalopods) from prawn trawls, the percentage of each group that floated, and the percentage of each group that was alive 12 hours after a 30-minute exposure to air on deck. Source: Hill and Wassenberg 1990.

	Composition (%)	Floating (%)	Surviving (%)
Fish	78 (62-90)	45 (29-59)	2 (1-3)
Crustacea	18 (9-33)	0 (0)	51 (23-80)
Cephalopods	3 (1-6)	26 (0-59)	2 (0-12)
Total		37 (23-49)	11 (7-17)

Table 17b. Percentage of animals surviving for 12 hours after exposure for 10 minutes on deck. Note: n *is at least 30 in all cases; animals collected from trawls of 30-minute duration. Source: Hill and Wassenberg 1990.*

Taxon	Percentage survival
Crustaceans	
Stomatopods (*Squilla* spp.)	50
Crabs (mainly portunids)	100
Molluscs	
Cuttlefish (*Sepia* spp.)	0*
Squid (*Loligo* spp.)	0*
Echinoderms	
Starfish (*Astropecten* spp.)	88
Teleosts	
Carangidae: *Carangoides caerulopinnatus*	13
Caranx bucculentus	29
Selaroides leptolepis	66
Leiognathidae: *Leiognathus splendens*	0*
Lethrinidae: *Lethrinus fraenatus*	43
Lutjanidae: *Lutjanus japonicus*	33
Mullidae: *Upeneus sulphurus*	0*
Upeneus sundaicus	0*
Nemipteridae: *Nemipterus furcosus*	0
Priacanthidae: *Priacanthus* spp.	3
Siganidae: *Siganus canaliculatus*	56
Teraponidae: *Pelates quadrilineatus*	50
Terapon theraps	97
Tetraodontidae: *Lagocephalus scleratus*	0*
*All dead within 1 hour.	

Berghahn et al. (1992) provide discard survival data for a number of bycatch species taken by shrimp vessels in the North Sea. Survival of flatfish is noted to depend strongly on the species and the size of specimens, as well as the catch processing conditions. A series of experiments on dab survival resulted in discard mortalities ranging from 0% to 67%, with an average mortality of 32.6% for fish collected after "sieving"[9] and 11.9% for dabs collected from the catch before "sieving" (Table 18). Additional data on the mortality of fish taken in shrimp fisheries are also provided in the Berghahn work (1990) in the Wadden Sea (Table 19).

[9] Sieving refers to an onboard sorting system.

Table 18. Dab mortality from shrimp fishery bycatch. A = after sieving out; B = results of controls with samples collected from the catch before sieving; TL= total length; Catch = total catch in one codend; N_b = number in the beginning; N_e = number at the end of the experiment. Source: Berghahn et al. 1992.

Date		TL Range (cm)	Catch (kg)	Water Temperature (celcius)	Duration of Experiments (d)	N_b	N_e	Mortality (%)
5/23/88	A	10.5-21	100	12-13.4	5.5	63	46	27
	B	12-22				26	23	12
8/2/88	B	14.5-24	50	17.2-17.4	5.5	40	31	23
8/8/88	A	12-20.5	70	18.0-18.8	5.5	6	2	67
8/15/88	A	9.5-20	70	17.6	5.0	13	8	38
5/15/89	A	12.5-20	110	12.0-14.0	6.0	19	17	11
5/21/89	B	10.5-23.5				20	20	0
	A	12-27	55	15.0-15.2	6.0	81	54	33
5/28/89	B	12-26				45	40	11
	A	10.5-25	150	15.7-14.4	5.5	31	23	26
7/49/89	B	11.5-25.5				11	10	9
7/25/89	B	20-20.5	75	15.0-16.0	5.0	2	2	0
5/10/90	A	20.5-26	125	17.2-17.5	5.5	5	4	20
	A	7-19.5	40	16.0	5.0	33	17	48
5/16/90	B	11-16				2	2	0
7/20/91	A	7.5-25	15	14.0-13.6	4.0	40	23	43
	B	12.5-25	50	16.7-17.5	5.0	12	12	0
Average					A	291	196	32.6
					B	159	140	11.9

Table 19. Mortality of selected fish species in the bycatch of the shrimp fishery after five days of maintenance. The trials without sieving are given in brackets. Source: Berghahn 1990.

Species	Number of Trials	Total Catch One Codend kg	Water Temp. C	Number of Specimens	Total Length cm	Mortality %
Dab	4	55-125	14.4-17.5	133	10-27	10-35
	(3)			(78)		(0.0-11)
Sculpin	7	70-150	14.4-18.8	52	10-20	0.00
	(3)			(17)		(0.00)
Hooknose	6	70-150	12.0-18.8	134	7-16	0.0-13
	(5)			(37)		(0.0-5)
Eelpout	4	70-100	12.0-17.6	45	13-20	0.0-17
	(4)			(28)		(0.0-13)

Chapter Summary

The term bycatch has different meanings among scientists. It may refer to (1) that portion of a catch taken by fishermen during the capture of a target species, (2) an assemblage of target species either retained or discarded, (3) discarded species only, or (4) that portion of non-target catch which is retained. In this study, we have chosen to use the operational definitions proposed by the Newport National Industry Bycatch Workshop. However, we recognize the need for an international effort to standardize bycatch and discard terminology and reporting modes.

Data for the world bycatch study were retrieved by the authors from literature searches, publications provided by fishery organizations throughout the world, and many independent scientists who have been concerned with the world bycatch issue. Books, publications, and gray literature acquired by the investigators have been placed in a special collection in the NRC library and can be accessed through a *FileMaker®* computerized information retrieval system. Additionally, a database has been created to access qualitative and quantitative information regarding discard rates in various areas of the world.

A total of 28.7 million mt of bycatch and 27.0 million mt of discard is estimated for world marine fisheries, although this total is considered to be conservative in that data are not included for many invertebrate fisheries, recreational fisheries, and subsistence fisheries. A great share (37.2%) of world discard occurs in various shrimp fisheries. Much of the discard in the shrimp fisheries is comprised of small tropical fishes, frequently weighing less than 100 grams. In temperate and subarctic waters, a great portion of the discard is comprised of juvenile and adult species of commercial value. Significant amounts of discard occur in many cod, hake, flounder, and crab fisheries.

Shrimp trawling almost universally results in high discard rates. High discard rates also occur in many of the world's trawl fisheries, although mid-water trawl rates fall among the lowest observed discard rates. Those for high seas gillnets were frequently among the lowest observed rates. Marine mammal discards probably constitute several hundred thousand a year. However, some reduction in marine mammal discards must have resulted from technical and operational changes in the ETP tuna seine fisheries and the discontinuation of high seas driftnet fisheries in the Pacific.

Survival of discards depends on a number of biological, environmental, and fishing operational patterns, but is believed to be low for most species.

PART II

BYCATCH AND DISCARD IMPACTS

CHAPTER 2 BIOLOGICAL AND ECOLOGICAL IMPACTS

Introduction

A great deal of concern has been expressed by fishery managers and conservation/environmental groups that bycatch and discards may be contributing to biological overfishing and altering the structure of marine ecosystems. Such claims are frequently based on observations of large numbers of discards and high discard ratios or rates as provided in the previous chapter, but infrequently on detailed population assessments of impacted stocks. This is perhaps because comprehensive and historical datasets involving discards have been unavailable to demonstrate such claims. Regardless, a growing body of literature does support the conclusion that for some species and regions of the world, biological and ecological impacts are discernible.

General Observations

Shrimp trawlers in the Australian northern prawn fishery (NPF) discard some 1.5 tons and 70,000 individuals per vessel per night of the fishery (Northern Territory of Australia Dept. of Primary Industry and Fisheries 1992). More than 240 species, including 75 families of fish, 11 of shark, and several of crustaceans and mollusks have been identified in the discard of some 30,000 mt of annual discards for this region. Fifty species and 28 families have been identified in the landed fraction of the Malaysian shrimp bycatch. A total of 59 families and 46 species were collected during bycatch research in the Philippines (Ordonez 1985). In Singapore, 51 families were catalogued in the landed bycatch. Juveniles of commercially important species accounted for 32% of the Singapore bycatch, while 48% of the bycatch represented low-valued species which could be used for direct consumption or processed into fish paste and other products (Abdullah et al. 1983). In the same study, roughly 20% of the bycatch consisted of species considered unacceptable for human consumption (Sinoda et al. 1978). Off Brazil, 147 species have been reported in the bycatch and total discards constitute billions of fish. Claims have been made that "the inshore trawling with small meshes is placing at risk the whole ecosystem of the region" (Conolly 1992). In the Gulf of Mexico shrimp fisheries, an estimated five billion croaker (*Micropogonias undulatus*), 19 million red snapper (*Lutjanus* spp.), and three million Spanish mackerel (*Scomberomonrus cavalla*) were reported discarded in 1989 (Murray et al. 1992).

Data for the 1992 Bering Sea pollock trawl fishery show discards of nearly 130 species, including over 100 million pollock, 8.5 million rock sole, 3.2 million Pacific cod, and 2.3 million flounders (NOAA/NMFS 1992). Another 200 million pollock were reported to be discarded in other Bering Sea groundfish fisheries. The aggregate discards in the Bering Sea and Gulf of Alaska bottom fisheries approach 1 billion animals annually, exclusive of discards occurring in the inshore salmon and herring fisheries and offshore crab fisheries. In the North Sea, the Northeast U.S., some areas of West Africa, and off Brazil, discards of some species are reported in many years to equal or exceed the landed catches.

Although the aforementioned numbers are enormous, that alone is insufficient basis for *de facto* inferences about their biological or ecological impact. The 300+ million pollock discards observed in the Bering Sea in 1992, for example, represent 1.6% of the exploitable numbers of pollock in the Bering Sea, and for most years pollock discards constituted about 0.5% of the exploitable pollock biomass. Squid driftnet fisheries were frequently called "walls of death" (Nobbe 1990) and an "enormously wasteful fishery that vacuums life from the sea leaving a biological desert in its wake" (Campbell 1991) prior to the international driftnet ban which went into effect in 1992. Yet the present study of global discards demonstrates the rates of squid driftnet discards per number of retained individuals in the South Korean and Taiwanese fisheries are some of the lowest observed for any gear type in any fishery in the world. Of the 60+ species discarded in the squid driftnet fisheries, two populations appeared to be unable to support bycatch harvest levels like those observed in the Japanese squid driftnet fishery (Sidney Review 1991). For one of the two species, leatherback turtles, the severity of the effects "may vary from insignificant to very significant, depending on the stock composition of turtles taken by the squid driftnet fishery" (Sidney Review 1991).

Obviously, large quantities or numbers of discards do not necessarily equate with significant biological or ecological impacts. Conversely, to presume effects are minimal or absent because discard quantities or rates are low may also be misleading. Impact studies which bridge the gap between discard quantities and the consequences of these losses at the population and community levels are a necessary prerequisite to improvements in our understanding of the effect of fishery discards on biological populations and marine environments.

The impact of discards on non-target populations may differ significantly from the effects felt by target species and may depend on life history features of the impacted species. Species having life history strategies similar to the target species may not suffer to the same degree as those species with significantly different life history features. For example, species having low reproductive rates, elevated parental care, and low rates of natural mortality, "k" strategist species, may suffer greater impacts than "r" strategist species, especially if target species fishing strategies and quotas are "r" strategy based. Thus, the impacts of high discard

numbers on cod, pollock, and flounders may be less than relatively low discard numbers on marine mammals, turtles, sharks, skates, and other similar species.

However, discards of small fish may generate very high levels of discard mortality that can impact even "r" selected species. Thus, discarding may contribute in a major way to problems of growth and recruitment overfishing in the directed fisheries and result in significant reductions in population levels of non-targeted species. Various studies have demonstrated bycatch and discards can alter the character of species assemblies (Wassenberg and Hill 1987; Hudson and Furness 1988; Blaber and Wassenberg 1989). Such shifts have the potential to alter predator/prey relationships, increase food for scavengers, modify the structure and function of benthic communities (as the result of oxygen depletion), and increase competition between fishers, marine mammals, and other sea life for the available resources. Although these impacts are more often inferred than demonstrated by careful research, the body of evidence supporting such claims has markedly increased over the past decade.

Population Level Impacts

A number of recent studies tends to confirm bycatch and discards are negatively impacting the levels of target species and non-target species. High discard rates of undersized target species in the Gulf of Maine groundfish fisheries have been identified as a contributing factor in population declines observed in the region (Saville 1980). In the Irish Sea, Brander (1981) notes the decline and scarcity of the once abundant common skate (*Raja batis*). Evidence strongly supports bycatch in the major groundfish fisheries as the reason for the demise of this species. Further, in the North Atlantic, minimum landing sizes for cod, haddock, and whiting in the mixed fishery lead to harvests of undersized cod and haddock which are, in turn, discarded. Chapter 7 discusses age-specific fishing mortality rates induced by discards for haddock and whiting. Discard mortality[10] is responsible for 20%, 81%, 54%, and 16% of ages 1-4 fishing mortality, respectively, for haddock and more than 15% of fishing mortality for all whiting age classes under age 5. At these mortality levels, discards clearly exert a strong pressure on sub-adult population numbers. A lower overall exploitation rate which would tend to push harvest pressure away from the minimum legal sizes and, thus, lower discard mortality on immature individuals is suggested.

Many large-scale tropical and subtropical shrimp fisheries suffer from growth overfishing as a result of premature capture of juvenile shrimp on estuarine nursery grounds. Nevertheless, this overfishing problem is not the result of bycatch discarding, and significant changes in shrimping effort do not appear to cause sizable swings in yield, suggesting recruitment overfishing is not a big factor regarding shrimp population dynamics. However, shrimp fisheries are known to

[10] Discard mortalities are based on instantaneous mortality values (F).

harvest large quantities of fish and other sea life and can impose heavy mortalities on non-target species (Blaber et al. 1990).

Studies on the impacts of shrimp fishery discards on finfish species and turtles in the Gulf of Mexico demonstrate reductions in population levels of non-target species. At least one non-target species, the Atlantic croaker, is reported to have declined to 40% of its abundance reported in the 1970s (Tillman 1992). Croaker in the Gulf of Mexico are described by Chittendon and McEachran (1975) as being a good example of the effects of overfishing on an incidentally captured species. It is noted the catch of croakers now consists almost entirely of a single year class of small fish in contrast to several year classes of much larger individual fish sizes in the 1950s. Between 1972 and 1989, 7.9 billion croaker a year were taken in the shrimp fishery (NOAA/NMFS 1992). Further, the Gulf of Mexico Fishery Management Council recently reported, as the result of a comprehensive stock assessment program in 1990, that the principle cause of fishing mortality on red snappers was from discarding in shrimp trawlers (Tillman 1992). Stocks of many other non-target species are known to have declined in abundance. Stock assessment modeling of Atlantic weakfish taken in the shrimp fishery demonstrates discard mortality may have a substantial effect on the long-term population level of this species.

Of course, species of little commercial or social value, such as the large amounts of discard in the tropical shrimp fisheries, may also experience discard mortalities. These species can serve as forage for or predators of commercially valuable species and make contributions to the trophic web. In addition, species of currently low economic value may become important target species in the future. Sturgeon (*Acipenser* spp.), for example, were considered a nuisance in the Columbia River salmon fisheries of the 19th century (Bricklemyer et al. 1989/1990). Consequently, thousands of sturgeon were caught and discarded, resulting in a population that is now a fraction of its original size.

Sharks are taken incidental to the harvests of many target species. Fisheries directed at sharks, particularly those for fins only, also occur. Some experts now believe total removals of the low fecundity and long-lived sharks are high enough to harm certain species. The U.S. has announced regulations limiting commercial and sport harvests and ban the practice of "finning"[11] (Satchell 1992).

Contrary to the preceding paragraphs, sizable amounts of discards do not always result in significant impacts at the population level. In the Northwest Atlantic, from 20 mt to 2,000 mt (up to 108 million individuals) of redfish (*Sebastes* spp.) are reported discarded each year, although these removals account for less than 2% of redfish stock biomass and 3.4% of the standing population size in numbers (Atkinson 1984). However, the stocks of redfish off the Northeast United States are currently at very low levels and the yield is stated to be only 51%

[11] "Finning" is the practice of cutting off a shark's fin and then returning the animal to the ocean.

of its long-term potential. Thus, any added fishing mortality will serve to slow the pace of fishery recovery. In the Bering Sea, discards of pollock, cod, and sablefish (*Anoplopoma fimbria*) constitute less than 10% of the observed fishing mortality for these species (Table 20). Because such losses are counted against the TAC, discarding is an economic concern rather than a problem of unobserved or unaccounted for mortality. Discard mortalities imposed on rock sole (*Lepidopsetta bilineata*) and unidentified flounders (*Pleuronectidae*) exceed the mortalities caused by the landed catch. However, the combined discard and reported fishing mortalities for rock sole and flounders are sufficiently low to prevent overfishing, and hence in this instance discarding involves a wasteful fishing practice. For rockfish (*Sebastes*), a group historically suffering from excessive fishing, discards account for about one-half of the total fishing mortality.

Table 20. Annual discard mortalities by species and the percent of total fishing mortality attributed to discards for fisheries in the Northeast Pacific (Bering Sea). Source: NRC and the NMFS.

SPECIES	ESTIMATED DISCARD MORTALITY (1992)	PERCENT OF TOTAL FISHING MORTALITY
Pollock	0.016	9.4%
Pacific cod	0.013	6.8%
Atka mackerel	0.008	15.1%
Rockfish	0.004	50.0%
Yellowfin sole	0.012	26.1%
Sablefish	0.001	1.9%
Rock sole	0.015	55.6%
Flounder	0.02	83.3%
Pacific Ocean perch	0.005	14.3%
Halibut	0.08[12]	24.0%

Preliminary results like those presented above demonstrate the importance of documenting discard mortality. Such information is needed to get a firmer fix on the fishing mortalities impacting marine populations. Furthermore, the collection and analysis of discard impacts and the levels of imposed mortalities provide insights into potential community-level impacts not detectable from landing statistics alone.

[12] Mortalities imposed on halibut having their origins in the Bering Sea increase to about 8% because of bycatch taken in the Gulf of Alaska.

Changes in Species Assemblages

As a result of the different quantities and mortality rates imposed on target and non-target species, species assemblages of a region may be altered. Prior to the introduction of shrimp trawling, the families *Leiognathidae, Ariidae, Carangidae, Nemipteridae,* and *Pomadasyidae* dominated the marine community along the Terrengganu Coast of Malaysia (Chan and Liew 1986). The abundance of *Leiognathidae,* a family commonly taken and discarded in tropical shrimp fisheries, dropped sharply after trawling commenced. A similar pattern was noted in the Gulf of Thailand where *Leiognathidae* and *Dasayatidae* numbers fell significantly over a period of ten years of shrimp fishery exploitation (Pauly and Neal 1985). Harris and Poiner (1990) have noted certain demersal species discarded in the Gulf of Carpentaria declined in abundance over a twenty-year period, while some pelagic components of the catch increased in abundance.

Fishing mortality effects, including discard mortality, on species assemblages can also cross trophic levels and affect predator/prey relationships. Gulf of Alaska resource assessment surveys conducted in 1960 were dominated by several species of flatfish, king and Tanner crab, Pacific cod, Pacific Ocean perch, and sculpins. A decade later, walleye pollock abundance far surpassed that of any other species in the survey, with Pacific Ocean perch abundance dropping from 36.8 kg to 3.9 kg per trawl hour. Crab abundance also dropped, while the weight per unit of effort for flatfish remained generally stable to increasing (Ronholt et al. 1978). These changes are reported to have resulted from large increases in fishing effort, particularly by the Soviets and Japanese, in the Gulf of Alaska (Alverson 1992b).

Discard mortalities are known to have contributed to species structure changes observed in the Gulf of Alaska. For example, Pacific Ocean perch (POP) harvests reached 350,000 mt in 1965. Although discard rate data were not available from the 1960s, the application of recently collected Gulf of Alaska POP trawl discard rates to the 1965 POP fishery suggests the real fishing discard mortality imposed on this stock may have been 20% higher and led to an actual catch of about 420,000 mt. Not surprisingly, POP catch per unit effort fell from 50-100 kg/hour in the early 1960s to less than 10 kg/hour by the mid-1970s (Shippen 1984). Pacific Ocean perch populations have yet to recover to levels observed in the 1960s.[13]

Other work has shown the removal of juvenile predators may actually increase prey mortality (Browder 1981). Energy-flow models of the Gulf of Mexico shrimp fishery demonstrate the shrimp fishery there is capable of influencing groundfish predator populations. However, because this mortality reduces the abundance of prey similar in size to shrimp, predation pressure on the

[13] Although discards probably contributed to the collapse of the *Sebastes* population in the Gulf of Alaska, miscalculation of the age also led to unrealistic estimates of yield potentials.

shrimp could increase. It is speculated that predators, having fewer options to select from, focus their attention on what remains, in this case the shrimp.

Environmental Impacts

Bycatch and discards also have led to changes in benthic community structure. It has been observed trawl ground gears can penetrate up to 6 cm into bottom sediments and otter boards have been found to dig into the bottom to a depth of 0.3 meters (Caddy and Iles 1972; Arntz and Weber 1970; Krost et al. 1990). Obvious mortalities are generated when benthic species are brought to the surface and then discarded. Not the least of these are mortalities due to increased predation following the redistribution of benthic species into surface waters and on the seabed.

Nevertheless, habitat modifications resulting from discarding may, at times, be confused with habitat modification resulting from the gear itself, or with "unobserved fishing mortalities." Because habitat and individuals can be damaged, but not brought to the surface, the extent of discard versus gear-induced mortalities may be difficult to quantify. A scallop stock inhabiting the Bass Strait in Australia was essentially eliminated within nine months of the start of a commercial fishery for scallops in the region. Much of the problem was related to an infection caused by decomposing scallops which had been crushed or damaged incidental to the scallop trawl operations. Researchers suspected that four to five times as many scallops were crushed or damaged as were landed (McLoughlin et al. 1991). In New Zealand, several deepwater fishing grounds have been exploited for the first time in recent years. Changes in bottom structure due to discards and trawl damage on these grounds were inferred from reductions in the number of invertebrate fauna brought to the surface over time (Jones 1992).

Grounds poisoning or spoiling is another indirect effect of discards on the benthic community. Poisoning refers to oxygen depletion occurring when non-target catch and processing waste is discarded at sea. If sufficient quantities settle to the bottom, decomposition processes consume enough oxygen to introduce anaerobic conditions. In general, if the discards are low in volume and returned over a broad area as the vessel is moving, it is assumed the discards are consumed by scavengers in the water column or on the bottom. In such instances the chances for depletion are minimal. However, local effects are possible and can be severe if heavy levels of discards occur.

Although unconfirmed, the dumping in 60 days of some 47,800 mt of discards in the New Zealand west coast hoki (*Macruronus novazealandiae*) fishery was projected to reduce oxygen saturation to 45%-55%. In the Northeast Atlantic *Nephrops* fishery, individuals often are "headed" at-sea and the "heads" discarded overboard. The presence of these heads on the bottom has been found to inhibit *Nephrops* bottom movements (Chapman 1981), thus "spoiling" the ground. The

benthic community structure also may change if a greater proportion of the community is comprised of scavenger or decomposer species attracted to the area (Bricklemyer et al. 1989/1990).

Impacts Enhancing Population Levels

Not all of the biological or ecological impacts of discards are considered negative. Hill and Wassenberg (1990), for example, note that "discarding from trawls has the effect of transferring large quantities of biological material from the bottom to the surface. This makes available to surface scavengers food that would otherwise be inaccessible." In all likelihood, discarding provides ready forage for surface, midwater, and benthic scavengers. Birds, sharks, dolphins, and other marine mammals commonly scavenge for food discarded in fishing operations.

Population increases for some sea birds inhabiting the North Sea have followed changes in prey availability brought about by altered fishing patterns. Primarily as a result of the at-sea discard of non-target species and processing wastes, the number of scavenging sea bird pairs in the North Sea region has risen from 37,000 in 1900 to 614,000 recently (Furness 1993; Hudson and Furness 1988). Birds, seals, and fish were found to be capable of consuming discards in fisheries located in the Wadden Sea (Berghahn 1990). Three species of sea birds are dependent on shrimp fishery discards in Moreton Bay, Australia (Blaber and Wassenberg 1989). Studies conducted in the Australian northern prawn fishery have shown benthic scavengers consume a considerable portion of the discards reaching the bottom (International Conference on Shrimp Bycatch 1992). Steller sea lions have been observed opportunistically following factory trawlers and consuming discards and processing wastes released by these vessels (Perez and Loughlin 1991).

Population enhancement of selected species due to discards may be offset by negative, but unobserved, impacts elsewhere. For example, species scavenging in and around fishing gear also increase their own susceptibility to incidental capture (INPFC 1990). However, population enhancements resulting from discards should not be neglected when considering how to deal with discards in the future. In the case of the changes in sea bird populations noted in the North Sea, a strict ban on discarding may lead to substantial population shifts away from conditions that have been almost a century in the making.

Impacts on Marine Mammals, Turtles and Birds

Marine Mammals

Bycatch and discards have also been shown to influence the population characteristics of marine mammals, sea birds, and sea turtles significantly. Vaquita

(*Phocoena sinus*), a species of harbor porpoise inhabiting the Gulf of California, is taken as a bycatch in the gillnet fisheries of the Gulf. Although the target fishery for totoaba, where many of the incidental takes occur, has been banned, illegal fishing and the stock assessment fishery continue to remove some vaquita (IWC 1991). The vaquita is considered the most endangered marine cetacean in the world, and further incidental takes carry obvious implications.

Fishing practices, including the bottom snagline, are among several factors contributing to mortalities of the baiji (*Lipotes vexillifer*), or Chinese river dolphin. Additional fisheries enforcement measures have been introduced to protect the species, but only 300 individuals are believed to survive. Harbor porpoise kills in the Gulf of Maine sink gillnet fishery for groundfish are thought to be at least equal to and may be greater than the population growth rate of the stock of harbor porpoise (Murawski 1994). Additional harbor porpoise mortalities are added by the salmon gillnet fisheries off western Greenland, Newfoundland, and Labrador, and some are taken in cod traps. In a report to the International Whaling Commission, Bjørge et al. (1991) have stated these takes are "cause for concern." However, mortalities of 2.5% of female Hooker sea lions (*Phocarctos hookeri*) in the trawl squid fisheries off New Zealand are not thought to be contributing to population changes there. Steller sea lion population changes in the North Pacific in recent decades are thought to be a result of several factors, not the least of which is a shift in the forage community structure caused by overharvest or environmental fluctuations impacting species abundance (Alverson 1992b).

Impacts of cetacean mortalities in passive gears were addressed at a 1991 IWC Workshop where scientists noted seven of 54 species population regions (SPR) had mortality rates for passive gears determined "to be not sustainable" (IWC 1991). Populations noted to be suffering from excessive mortalities included the baiji, the vaquita, the Indo-Pacific hump-backed dolphin (*Sousa chinensis*), two populations of bottlenose dolphins off the coast of South Africa, harbor porpoise in the Northwest Atlantic, and striped dolphin in the Mediterranean.

Considerable concern over declines in several populations and species of dolphins has been raised by scientists who have studied the impacts of bycatch in the ETP tuna seine fisheries. Fortunately, the populations in question have been stable for more than a decade and declines appear to have halted in the late 1970s. A recent study by the National Research Council concludes at present "the Eastern spinner dolphin (*Stenella longirostris*) is the subject of concern and is currently being proposed for depleted status under the U.S. Marine Mammal Protection Act." However, the Council's report notes "estimates of numbers as a fraction of pre-fishery numbers vary widely because baseline estimates of pre-fishery numbers are low and because estimates of mortality rates--themselves very imprecise for the years before the mid-1970s--are used in calculating numbers." Further, spotted dolphins (*Stenella attenuata*), subject to the greatest mortality in the ETP tuna seine fishery, "seem not to have been depleted as much as spinners." Regardless, the evidence is clear that in the early years of the fishery, bycatch mortalities

were significantly reducing population sizes of "the most commonly taken dolphins." However, by the early 1970s, kill rates began to decline, and population sizes of impacted species have since stabilized. Reduction in mortalities were reported to result from (a) training of skippers to perform backdown procedures, (b) helping quiescent dolphins from the net, and (c) making gear modifications.[14]

Seabirds

Numerous seabirds are taken in gillnet and other fisheries. The importance of sea bird takes increases when such takes come from small local populations. From 2.1% to 9.3% of various populations of gannets (*Sula bassana*) are reported discarded annually in gillnet fisheries near Newfoundland (Piatt and Nettleship 1987). In the early 1980s, roughly 12% of Newfoundland's breeding population of razorbills (*Alca torda*) were killed each year in gillnets. As much as 16.3% of some adult common guillemot (*Uria aalge*) populations were killed by gillnets in and around Newfoundland in 1982 (Piatt and Nettleship 1987). Further, although the numbers are much smaller, the 200 annual mortalities of marbled murrelets (*Brachyramphus marmoratus*) in Barkley Sound, British Columbia, represent a considerable take from the population residing in the area (Coleman and Wehle 1983). Concerns that incidental takes in the salmon net fisheries may be damaging the marbled murrelet population have led to the introduction of a comprehensive on-board observer program in the purse seine and gillnet fisheries of northern Puget Sound, Washington.

Sea Turtles

Incidental takes of sea turtles in shrimp trawls have drawn a great deal of attention in recent years. Shrimp trawl bycatch of sea turtles has been identified by the National Research Council (1992) as the most significant source of sea turtle mortality in the United States. Since all five species of sea turtles found in the United States are listed as either threatened or endangered, effective controls on all sources of additional mortalities, including bycatch, have been encouraged. After years of development and testing, regulations requiring the use of Turtle Excluder Devices (TEDs) were issued in 1987 (Renaud et al. 1991). Because of concerns over crew safety and reduced shrimp harvesting efficiency, TED use was and still is contested by many shrimp fishermen. Nevertheless, the use of TEDs and Bycatch Reduction Devices (BRDs), which allow non-target fish and turtles to escape, is increasing.

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[14] For a more comprehensive review of both direct and incidental catches of small cetaceans, the reader is referred to the Bjørge et al. (1991) report on "Significant Direct and Incidental Catches of Small Cetaceans" and the report on the "Incidental Capture of Marine Mammals" recently published by the Center for Marine Conservation (Young et al. 1993).

Crouse et al. (1987) found mortality of juvenile loggerheads (*Caretta caretta*) in shrimp trawls was preventing recovery of this threatened species. In a letter (to the authors), Crouse noted:

> A National Academy of Science (Magnuson et al. 1990) study panel, assessing the causes of declines of sea turtle populations in the U.S., pointed to incidental capture and drowning in the shrimp trawl fishery in the southeastern U.S. and Gulf of Mexico as the "major cause of mortality associated with human activities, [killing] more sea turtles than all other human activities combined." The panel estimated that as many as 50,000 loggerheads and 5,000 Kemp's ridley sea turtles (*Lepidochelys kempii*) drowned annually in this fishery in the 1980s. This is a particular concern for the Kemp's ridley, since the world's adult female nesting population is estimated to be fewer than 1000 individuals (USFWS and NMFS 1991). Regulations expanding requirements for turtle excluder devices (TEDs), which exclude 97% of the non-leatherback turtles captured, in all U.S. shrimp trawls by December, 1994 were published in December, 1992 (57 FR 57348-57359). Since sea turtles are very slow to mature (green turtles (*Chelonia mydas*) may not become reproductively mature until 30-50 years of age), it may take decades to see the effects of management actions such as TEDs. Likewise, this unusually long juvenile period, combined with high mortality of eggs and the early life stages, leaves sea turtles populations highly vulnerable to losses of reproductive and soon-to-be-reproductive individuals (Crouse et al. 1987; Magnuson et al., 1990).
>
> Beyond the shrimp trawl fishery, a number of other fisheries are implicated in sea turtle incidental capture and mortality, however, quantitative data are very hard to come by. Also, as mortality in the shrimp trawl fishery is reduced through the use of TEDs, the frequency of capture in other fisheries appears to be increasing, probably because there are more turtles available to be captured in these other fisheries. In general, otter trawls, gill nets (both anchored and drift) and long lines appear to take significant numbers whenever they co-occur with sea turtles. Other fishing gear types, such as pound nets and purse seines, also capture sea turtles, but they are usually released alive, unless intentionally injured (or eaten) by the fishermen.

Leatherback, loggerhead, and green sea turtles, of which leatherback and green are listed as endangered by the IUCN, were taken in the North Pacific high seas squid driftnet fisheries (FAO Sidney Review 1992). Loggerhead and green sea turtle discard mortalities in the same fishery were low and judged as having an insignificant effect on population characteristics. The severity of leatherback

impacts was uncertain because scientists were not sure whether the turtles emanated from the Mexican or Malaysian breeding stocks. The Mexican stock is reportedly quite healthy and could support some incidental takes without consequence. Unfortunately, the Malaysian stock is depressed and additional mortalities induced by incidental takes in the driftnet fishery could worsen its condition.

Chapter Summary

Although a number of ideas have been put forth regarding the consequences of discarding in marine fisheries, supporting evidence of impacts at population levels, as well as ecological impacts, have been sparse until recent years. Nevertheless, there is a growing body of evidence clearly demonstrating the serious character of discarding of various marine populations, including some fishes, marine mammals, and turtles. Discarding can be shown to be a significant component of the fishing mortality for species in the North Atlantic, Gulf of Mexico, and Bering Sea. For all world fisheries suffering from growth overfishing, discards are a component of the fishing mortality. Long-term alterations to species assemblages are detectable in many regions, although it is not readily discernible what roles are played by removals of target and non-target species, unobserved fishing mortality, and habitat modifications caused by fishing gears.

CHAPTER 3 ECONOMIC IMPACTS

Discards introduce a variety of biological, ecological, and social costs. This chapter will focus on those purely economic in nature. Recent assessments of the economic impact of discards on commercial fisheries describe a set of costs far from trivial. Murawski's (1994) analysis of the Northwest Atlantic groundfish fishery found that $50 million of income was forgone to the local trawl fisheries as a result of the premature harvest and discard of the 1987 year class of yellowtail flounder. The value of the Gulf of Maine fisheries could double if discarding could be eliminated (Chapter 6). NRC (1991a) estimated the value of the prohibited species (crab and halibut) losses in the Bering Sea groundfish fisheries as $160 million[15] at the first wholesale level. Losses due to discards in the Bering Sea crab fisheries contributed an additional $50 million loss. Earlier evaluation (NRC 1990) placed the value of non-target removals of crab, halibut, and salmon in Gulf of Alaska fisheries lost because of regional discards at between $20 million and $30 million per year. The aggregate Bering Sea and Gulf of Alaska losses of commercially harvested species resulting from discards has thus been in excess of $250 million annually.

These studies provide informative insights into the economic costs of discards. Unfortunately, few such studies exist, and consequently we are left with little more than a skeletal picture of the global scope of economic costs imposed by fishery discard. For example, we note:

1. In the North Sea bottomfish fishery, the discard of marketable species equals the reported landings for the fishery.

2. Off the Brazilian coast, discards in the trawl and shrimp fisheries are comparable to the size of the total landed catch.

3. Off the U.S. East Coast in the Gulf of Maine discards of demersal species range from 35% to 79% of landed catch volume (Chapter 6).

4. In many of the world's crab fisheries, numbers of discards significantly exceed landed numbers, and the weight of discards may also exceed the weight of landings.

If these discard costs are even remotely accurate, the aggregate economic losses due to discards in many fisheries and regions of the world may easily approach the value of landed catches. Unfortunately, a definitive test of this hypothesis is not possible, based on the current database.

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[15] Due to lost harvesting opportunities of the trawl fleet.

Because the origins of discard costs are diverse, various authors have suggested such costs be aggregated, based on specific criteria. The classification used by Smith and Lloyd (1989) is particularly informative because it relates economic impact to the group bearing the burden of the identified costs. The authors indicate discard impact costs are felt by those harvesting, processing, marketing, or consuming any species discarded by the target fishery. Control costs are the costs of measures taken by a fishery to minimize its discards. A final category, management costs, is tied to measures attempting to regulate discards. While we agree the cost categories Smith and Lloyd specify correctly describe the types of costs associated with discards, measurement realities make it difficult to assess each of these cost groups separately. Overlap unavoidably ensues. Consequently, in this chapter we have chosen to use a slightly different analytical paradigm, one aggregating the trilogy of coasts delineated by Smith and Lloyd into two broad groups. These two categories, the costs associated with the act of discarding and the costs tied to objectives of monitoring or preventing discards, provide a useful basis upon which to analyze the economic consequences of discards.

Impacts Associated with Discard Mortalities

Discards of Species of Commercial Value to Other Fisheries

In terms of estimates of economic losses imposed by discards, most published studies investigate discard mortalities induced by a fishery on species of commercial value to other fisheries. For obvious reasons, these sorts of mortalities often spawn bitter conflict between fishers and lead to inter-gear battles and political infighting over resource allocation and bycatch removal quotas. Finding a solution minimizing losses to all gear types, or which satisfies society as a whole, is not an easy task. Complex sets of impacts and counter-impacts occur in all multigear fisheries.[16]

Linear programming analysis of various bycatch management strategies for the Bering Sea multi-species groundfish fishery was used by NRC (1991a) to search for an optimal solution to the catch and discard problems of the region. Using the extant fleet size, target species catch quotas, and bycatch rates collected by onboard observer programs, the NRC study searched for mixes of fishery start dates, quotas for Alaska pollock, and discard species allocations that would reduce the current

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[16] Catching juveniles of a target species may represent an economic loss in terms of foregone economic yield-per-recruit for the misbehaving fishery whether or not they are discarded. The losses are higher if they are discarded, since there are no short-term benefits. However, in most cases, there would be a cost in non-catching the juveniles associated with losses of the target age groups when trying to avoid non-target individuals or expenses due to costs for different gear. If, as in sequential fisheries, the losses are provoked by one fleet (which catches juveniles) but are incurred by another fleet (which targets older age groups), this type of allocation must be taken into account in any corrective measure.

estimated $150 million annual cost to halibut, crab, and salmon fisheries while maintaining positive net margins in the groundfish fleet.

The model revealed effective vessel-specific incentive or quota systems have great potential to reduce bycatch, new and uncomplicated fishery regulations can lower bycatch significantly, and benefits to the fishers and the nation can rise significantly in conjunction with the additional harvests these changes permit. It also revealed that crab fishermen in the region were their own worst enemy in terms of the bycatch losses they generate and that bycatch can vary tremendously from one vessel type to another. Furthermore, it became clear the current size and structure of the groundfish fleet would prevent it from attaining all of the potential benefits bycatch reduction could provide. Finally, sensitivity analyses altering discard survival rates demonstrated a reduction in the number of fish or crab that die after being taken as bycatch will, in and of itself, make a huge contribution to improving overall benefits.

Aside from the analysis of incentive-based management approaches, some specific regulatory options were investigated in the modeling effort. These uncomplicated scenarios were suggested by fishermen who felt changes, such as a shift in the start date of the Bering Sea groundfish fishery would take advantage of the different distribution of target and bycatch species at certain times of the year. A shift of the start date from the current January opening to November reduced the value of bycatch losses by 30% and permitted the harvest of more groundfish per dollar of bycatch loss than any other comparable model.

Another straightforward scenario required the harvest of the entire pollock resource with midwater trawl gear. This alternative lowered bycatch discard to the lowest levels of any model runs but, unfortunately, also reduced harvest and fishery revenues dramatically. In terms of bycatch discard reduction, performance of this option was exemplary. In terms of accrued economic and food production benefits to the nation, however, the strategy performed rather poorly.

One of the more interesting work products of the study was the finding that if effective bycatch management programs are put in place groundfish harvests almost reach Acceptable Biological Catch (ABC) limits before reaching bycatch quotas. This ABC-level fishery actually costs less in terms of bycatch losses than does the present fishery restricted to the lower Total Allowable Catch (TAC) levels.

Overall, the study demonstrated if fishers were permitted to use their individual capabilities to seek out the optimum mix of catch and bycatch, substantial reductions in aggregate bycatch are possible. The most striking results of the modeling effort were those showing a significant improvement in the bycatch picture (a 70% to 80% reduction in bycatch) with neutral side effects for the groundfisher would be possible if the profit-seeking fisher were given the incentive individually to improve the discard picture. Of course, the model selected those fishers making the best choices, and one could quite correctly argue

existing management systems do not operate in such a fashion. Instead, under current management regimes, the rational, profit-seeking fisher, recognizing bycatch quotas on the horizon, races to catch as much fish as soon as possible in order to minimize his loss when those quotas are reached.

Successful incentive programs might emerge if decisions were transferred to the level of the individual fisher through carefully thought out incentive or ITQ programs. The capacity of incentive programs to reduce discard levels is based on the ability of the fishers to use their collective experience to avoid areas where high levels of unwanted species or sizes of species are taken. Furthermore, fishers also have a clear understanding of the implications of success or failure of their efforts, with rewards for success and disincentives/punishment for failure. In most current management systems, such rewards (catch) and punishments (closures) are felt only at the fishery level. With the system of individual incentives/disincentives, individual fishermen have the capacity to control their status. Incentive programs, however, require some sort of accountability process which to date has largely been dependent on relatively costly observer programs.

Discards of Non-Legal Individuals

A second set of discard-induced mortalities carrying obvious economic implications is what is suffered when a fishery discards immature individuals or non-legal sexes of the same species group it is targeting. Several examples can be found of the benefits of minimizing such losses. Poffenberger (1982) determined shrimp harvest value increased $9.4 million following fishery closures off Texas, permitting juvenile shrimp to grow to more marketable sizes. NRC (1990) estimated annual losses of discarded sublegal or non-legal crabs in the Bering Sea crab fisheries might be as high as $40 million to $50 million in some years. Chapters 5, 6, and 7 in this study provide evidence of significant economic losses resulting from discarding of under-aged demersal fishes.

Disincentives for the capture of immature fish are now emerging in some fisheries. For example, in the Bering Sea groundfish fisheries discards and retained weights are deducted from TAC quotas. The cost to Bering Sea fishermen for the capture of immature pollock by their vessels and by pollock taken by fisheries targeting other species in 1992 is established at about $35 million.[17] That is, if the immatures were not taken, the increase in the catch of marketable pollock which would have occurred would have raised the value of the harvest by this amount. As already mentioned, however, such accountability is more the exception than the norm in today's fisheries management. Moreover, with the exception of systems like New Zealand's Individual Transferable Quota, accounting occurs at the fishery rather than at the individual fisher level, and such aggregated programs may serve less well as economic disincentives than do vessel- or fisher-based systems.

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[17] This loss reflects the increased dollar yield, assuming no change in quota would have occurred if immatures had not been taken. The estimate also assumes constant prices. It does not consider costs that might be incurred to avoid bycatch or the technology that might allow a zero bycatch level.

Much more attention needs to be directed at the cost of this form of discard mortality. With the exception of the large reduction fisheries, most commercial and recreational fisheries are directed at specific size/age classes optimizing economic performance, either on the factory line or for personal pleasure in the sport fishery. Until recently, the discard of non-legal or other-than-optimum sizes/sexes taken in conjunction with the target sizes/sexes has often been ignored in calculating real fishing mortality. Consequently, target quotas are met and fisheries closed only when the tonnage of legal/optimum-sized individuals is reached, despite the possibility that owing to discards, actual mortalities of the species induced by the fishery may be much higher.

Discards of Non-target Species of Little Commercial Value

A third and often overlooked stream of economic costs is associated with discards of non-target species having no economic value to a fishery. While at first glance one might question whether any economic cost can be associated with such removals, failing to account for such losses would neglect the often interdependent nature of species with and without commercial value.

Catching an unwanted species represents an economic loss because of (a) the cost of catching it, sorting it from the target catch, and throwing it back overboard, and (b) the foregone economic value of the discard if it were better exploited.

Costs can be tied to the longer on-deck sorting times necessary to separate and return prohibited or unwanted species to the water. For at-sea processors, lower factory throughput efficiencies and higher processing crew costs due to the additional time required to separate discards from the retained catch are the direct result of the presence of discards in the catch.

In our review of the discard literature, few studies of the actual costs such inefficiencies impose on a fishery have been identified. An index of such losses could be derived by an estimate of "wasted" effort units in a fishery. The value of each unit of wasted effort would reflect harvesting and processing costs and would be some function of the value of "effective" effort units.

While such an index would require scaling to a per-vessel level, ballpark figures offer insights into the scope of this form of economic costs. In 1992, pollock discards accounted for 6.2% of retained pollock harvests in the Bering Sea. For the sake of simplicity, if aggregate catch-per-unit-effort (CPUE) is related linearly to CPUE for retained individuals, then discard effort is a linear function of discard rate and total effort. Thus, for example, one can suggest 6.2% of the effort expended to harvest pollock in the Bering Sea in 1992 was wasted, since it was expended on pollock later discarded. Since data are available on the variable costs of factory trawl operations in the Bering Sea, it can be assumed the entire Bering Sea pollock harvest was taken by such vessels. (Actually, 1992 factory trawl

catches accounted for 68% of pollock harvests.) Under these assumptions, "wasted" effort in the 1992 fishery represented an economic operating cost of $1.03 million. While not a definitive response to interest in the inefficiency costs of discards, such an index does demonstrate such inefficiencies should not be overlooked in a rational assessment of total economic costs associated with discards.

If a discard species can be exploited by other sectors, such as turtle watching or another fishery, the value of discard losses depends on how much alternative users are willing to pay. There are also benefits when species take advantage of discards to proliferate. Discarded fish may bring profits to the cephalopod or shrimp industry by increasing food availability and abundance of the target resources.

In many cases, species of commercial value prey upon each other and on those with no commercial value. Removals of a prey species as a discard mortality may have measurable effects on the growth, survival, and reproductive conditions of the exploited species. If negative, these impacts can introduce costly economic effects into the fishery. Conversely, economic benefits may ensue if discard mortalities "fine-tune" the ecosystem, improve prey species populations characteristics, or remove predators which constrict survival of the commercially valuable species. Given our understanding, or lack thereof, of real between-species dependencies in the marine system, these potential economic costs have been largely unknown to date. As this knowledge grows, we should attempt to conduct ever more critical analyses of the extent of such costs.

A special case of the set of costs associated with the discarding of species with and without commercial value bears some mention. This unique situation is of growing concern, is often accompanied by changes to traditional bycatch use patterns, and involves the redistribution of income and landings from artisanal to larger, more mechanized vessels. Pauly and Neal (1985) in their discussion of Southeast Asia shrimp fisheries, notes one of the definitive characteristics of the modernization of the shrimp fleet in Southeast Asia is the trend toward longer trips. For economic reasons related to on-board storage space and the market value of shrimp compared to other species in the catch, a significant portion of the catch of finfishes is discarded. An unfortunate artifact of this trend is the reduction in landings of low-valued species which have historically served as a cheap source of protein for coastal populations and supported animal husbandry. Perhaps as the scarcity of such discarded fish worsens, their value will increase until a new equilibrium is established between landings, demand, and per-unit cost. However, the new unit cost of the bycatch fraction will undoubtedly be higher than it was prior to the modernization of the fleet. Such higher costs may well result in one of two possible scenarios for low-income or impoverished populations of Southeast Asia and other developing regions of the world--an increase in family expenditures to meet protein needs or a reduction in protein consumption.

Costs Associated with Monitoring and
Preventing or Reducing Discard Levels

The second category of economic costs associated with discards is tied to the objective of preventing or monitoring discards. Included within this category are management and enforcement costs and costs involving required modifications to gear and changes in fishing patterns in order to reduce bycatch.

The 1992 budget for marine fisheries management in the U.S. of approximately $200 million represented $0.045 of management expenditures per pound of landed harvest weight. It is difficult to determine just how much of this management budget was spent directly or indirectly on bycatch management, monitoring, or prevention. Let us assume, however, that 10% of U.S. costs were spent on discard concerns and that discard budgets in other nations are themselves just 50% of the U.S. allotment for discards. Doing so generates a global tab for discard-related costs of $4.5 billion. Even under conservative assumptions of expenditure allocations, costs associated with the management, monitoring, or prevention of discards are staggering.

Lost fishing opportunity constitutes another area of economic costs associated with discarding. For gear types discontinued because of discard impacts, losses to the involved fishery will be complete. Further, if alternate harvesting systems cannot be introduced for such fisheries, the economic loss to society is also complete, even though ethical and biological/ecological concerns may have been addressed. In fisheries where discard quotas exist, large quantities of target species harvests will be lost when these discard quotas are reached. Attainment of the discard quotas triggers selective species closure or generic, area-wide, across-species bans on fishing. Although such closures can limit the operation of all gear types, equity considerations typically result in restrictions on the offending gear type.

Potential economic costs associated with the closure of fisheries prior to the attainment of the target species quotas are neither trivial nor infrequent. In the Bering Sea in 1991, discard quotas contributed to the closures of the bottom trawl fishery for rock sole, pollock, cod, and flatfish, as well as crab pot fisheries for *bairdi* Tanner crab. Similarly, in 1990, discard quotas closed eight major fisheries in the region. In the Gulf of Alaska, the halibut bycatch quota has served as a barrier to the development of a large and economically valuable resource. The potential yield of flounders in this region is set at 442,000 mt, but less than 10% of the take is normally harvested. Access to these economically important flounder stocks are currently dependent on the evolution of more selective gear types or the relaxation of current prohibited species quotas. In addition to curtailing access to these species, in an open-access fishery such closures can complicate discard management in the region. As closures in one fishery push effort into other areas, the race for fish intensifies, and as closures approach, selective fishing practices minimizing discards may be ignored. Fishers frequently believe fish they don't

catch today may not be available for the taking tomorrow. Clearly, biological, if not economic, wastage is encouraged.

Of course, different management institutions use quotas in different ways. In the multi-species Northeast Atlantic groundfishery, for example, quota attainment for a species requires that species to be discarded overboard. Since many of these discarded individuals die, the management significance of such quotas is drawn into question. Perhaps a more biologically and economically sound approach is reflected in New Zealand's ITQ system. Here, quotas for discard species are subdivided among participating vessels and can be traded. Economic costs of quota attainment for a specific vessel are embodied in the costs associated with the purchase of additional discard quota. Presumably, as the supply of such unused discard quota dwindles, the per unit cost of the discard quota rises. When all such quota is exhausted, vessels without remaining quota are forced out of the fishery. Their costs become the value of their remaining inaccessible target quota less variable and discard quota costs that would have been expended had they harvested the quota. Such a system perhaps better reflects the true cost of discarding.

Observer costs are another item for which total expenditures should be prorated across discards and other fisheries management costs. However, given the presence of operational observer programs in the Northeast Pacific and elsewhere, per-unit observer costs are much more tangible than other management costs. After nearly four years of operation, observer costs associated with full-time coverage of vessels participating in the U.S. Bering Sea and Gulf of Alaska groundfish and crab fisheries range from $3,500 to over $5,000 per month. These costs are paid to observer contractors who hire qualified individuals and place them on contracted vessels.[18] Observer costs can clearly be substantial, and this in large part explains why observer programs have not been implemented more comprehensively. Faced with such costs, marginal vessels or even low-margin operations could be forced out of the fishery.

Enforcement costs associated with wild harvest commercial and recreational fisheries are substantial. In the North Pacific alone, U.S. fisheries enforcement costs total $80 million annually. Unfortunately, given the number of stocks currently overfished in global fisheries, ongoing problems with illegal fishing on the high seas and emerging concerns over high-grading and other means of economic poaching, current enforcement capabilities are not real deterrents to such actions. While some of the problems concerned with documenting discard levels can be dealt with through the use of observers, in many fisheries they may be impractical.

Another area of costs imposed when seeking to prevent discards is tied to gear or fishing pattern modifications mandated by bycatch regulations. Griffin and

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[18] We understand observer program costs in U.S. East Coast fisheries have reached monthly costs of up to $10,000.

Hendrickson (1992) estimated the present value of the use of bycatch reduction devices in the U.S. Gulf of Mexico shrimp fleet would represent a cost to the fishery of $16.4 million to $27 million over a ten-year period. Fishery closures mandating changes in fishing patterns would be still more costly--$35.2 million to $54.6 million. NRC (1991a) demonstrated the current pattern of fishing by bottom fishermen in the Bering Sea costs the industry and the nation from $30 million to $120 million per year.[19]

In many fisheries, current fishing practices and gear riggings produce discards carrying with them an assortment of economic costs. Gear modifications or alternative fishing approaches have the potential of reducing the catch of unwanted fish or shellfish, but at what expense to target catch and processing or handling rates? Break-even results may not be good enough to induce fishers to shift fishing practices; that is, unless real financial benefits can be associated with the new gear type/method, fishers will not voluntarily modify their behavior. Although regulations mandating the use of new gear have been imposed in certain fisheries, their effectiveness may be negated if there is strong user-group resistance to employing the new gear. The alternative then becomes the development of gear types, fishing strategies, or fishery management options that encourage fishers to adapt low discard rate practices.

Chapter Summary

Economic impacts flowing from discarding include (1) foregone catch as a result of mortalities imposed on recruits to the target fishery, (2) foregone catch resulting from mortalities imposed on target fisheries by fisheries targeting other species, (3) loss of fishing operations resulting from bycatch quotas forcing fishery closures when attained, (4) costs of purchasing new technology, (5) loss of catch when a gear type is outlawed, and (6) loss of catch due to capture of immatures subtracted from the TAC. Other economic losses result from required observed programs and sorting costs. In total, the loss of potential catch resulting from discarding or discard regulations amounts to billions of U.S. dollars, and in many fisheries the losses due to discard mortalities are noted to equal or exceed landed catches.

Much more work is needed to assess adequately the true economic cost of discards on fishers and the benefits and costs of potential solutions to society as a whole. We should not forget, however, that discarding is not all bad. Mortalities associated with discards may decrease key predator or competitor populations. Discards may increase prey availability and enhance system productivity. Furthermore, in many cases, discarding practices permit fisheries to remain cost effective. Currently, society views the benefits of such continued viability as

[19] Current approaches use fishery-wide quotas to control harvest. Such quotas result in a race for fish that produces a waste of fish. NRC found by moving the incentive to fish cleanly to the individual fisher level, discard losses would decline by $30 million to $120 million.

outweighing the potential costs imposed on marine ecosystems. Only in the last few years have environmental groups begun to use political pressure to promote commercial embargoes or trade barriers to overcome this problem. Much more work is needed to assess adequately the true economic costs and benefits of discards on fishers and the societies of which they are a part. Revised cost/benefit accounting procedures and better natural resource economics may offer the basis for more rational alternatives.

CHAPTER 4 SOCIO-CULTURAL IMPACTS

The nature of most economic, biological, and ecological variables is such that if an effect is suspected, measurement and evaluation of the underlying data can usually confirm or reject its presence. If confirmed, the effect can be further parameterized by its dollar value, weight, number, diversity level, or other indices. Thus, the value of the TAC no longer available to halibut longliners because of its removal as discards in the groundfishery is one measure of the economic effect of discards on the halibut fisher. Likewise, a reduction in population abundance due to the growth overfishing of a given species is an index of a biological impact and the elimination of a predator due to excessive discard mortality a reflection of ecological change.

Although disagreements over the presence or absence of an economic, biological, or ecological discard effect may occur due to debates over proper analytical methods or measurement errors, the described impact can usually be recognized by the participants in the fisheries of concern. However, the perception of the consequence of a discard impact or its importance may vary sharply between countries as the result of socio-cultural differences or their dependence on marine resources as a source of protein for their population, religious beliefs, and historical customs. Thus, the success of a proposed international fishery management strategy designed to reduce discard mortality will benefit from an understanding of the distinct attitudes of separate societies towards the biological, economic, esthetic, and ethical aspects of discards. To date, efforts to understand socio-cultural distinctions or different national dependencies upon marine resources as protein staples appear to have played little or no role in regional or international discard policy evolution. Instead, the issue of discards and the "correct" attitude towards them is clouded because each society clings tightly to the vision they believe appropriate. This is particularly true for the emerging bycatch policies that have impacted or will impact bycatch discarding in the ETP purse seine tuna fishery and the high seas driftnet fishery as well as the use of TEDs in world tropical shrimp fisheries.

Discard Conflicts Based in Socio-Cultural Differences

As a consequence of competing socio-cultural visions, the intensity of conflicts over the discard issue should not be surprising. From the perspective of many conservation/environmental groups in the U.S. and elsewhere, it seems appropriate and necessary to demand an embargo on shrimp from Indonesia due to turtle discards in these fisheries (*Seattle Post-Intelligencer* 1992). On the other hand, to the Indonesian shrimp fisherman whose principal source of income comes from the shrimp he harvests, such an embargo appears unfair and totalitarian. Oregon sport fishermen eager to implement a gillnet ban in state waters are likely to disregard the interests of commercial netters who have operated in the fishery for

generations (Fiorillo 1991). Dolphin-safe tuna marketing programs are lauded by many environmental/conservation groups on ethical grounds they protect marine mammals (Kronman 1992). Persuading these groups to take into account the differing concerns of impacted participants or to change their attitudes and management tactics based on technological advances may be difficult, if not unlikely. For example, a significant reduction in dolphin mortality has occurred in tuna fisheries setting on porpoise schools, making such gear theoretically more acceptable. Although the bycatch of juvenile yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and other pelagic fishes has been shown to be very high in some alternative seine fishing modes, efforts to outlaw the use of purse seines or ban sets on porpoise schools in tuna fisheries continue. Dr. Martin Hall of the IATTC (seminar, University of Washington 1994) noted:

> Many attempts have been made to solve the tuna-dolphin problem ranging from embargoes to consumer actions.... With dolphin mortality reduced 97% since 1986 and a projected mortality of 3,500 individuals for 1993, this is no longer a conservation issue. This question is now how to harmonize the different priorities and concerns, economic interests, cultural views, etc., of the countries involved in the fishery, in a solution that takes into account both the ecological and social angles of the issue.

Hall (1994) notes the need and difficulties of achieving truly multinational, science-based ecosystem management schemes.

In a similar twist of perception and reality, driftnets have been labeled "walls of death" at the same time Italian and Chinese fishermen have been encouraged to use them because of their reported conservation properties. Data demonstrates some driftnets have relatively low discard ratios. Furthermore, although the thrust of much of this volume is the documentation of bycatch discard quantities and the excessive nature of these losses, at the same time it is noted that some fishers encourage the development of shrimp trawls that take more fish because of potential sales into shoreside protein markets (Pauly and Neal 1985).

With each of these issues, who is right and who is wrong is largely a function of vantage point. After reviewing much of the literature describing the socio-cultural impasses resulting from discards, it appears such national and international standoffs are frequently driven by ethics, esthetics, or societal attitudes toward the consumption of various marine products.

Attitudes Toward Non-Consumptive Uses and Their Impact on Policy Formulation

Hartmann (1992), in his review of the World Fisheries Congress, states that "there is a bias in management towards the needs of the developed countries; the dynamics and ecological social importance of artisanal fisheries are ignored." Such

bias towards first-world interests goes much deeper than just management issues. Conservation and environmental protection attitudes are frequently seen as driven by U.S. and European societies. The 1992 Roper survey on U.S. National Resource Conservation attitudes in the 1990s (National Research Council 1992) offers some insights into the nature of these attitudes. About 80% of Americans consider themselves active environmentalists or sympathetic to environmental concerns. Two-thirds of the populace state they think environmental regulations have not gone far enough. Sixty to seventy percent of Americans also rank environmental concerns before economic ones when compromises between the two cannot be reached.

Environmental and economic concerns of the U.S. public lessen, however, as we move down the economic ladder in the United States. Thirty-eight percent of the least wealthy Americans, as opposed to only 21% of the most well off, believe economic issues outweigh environmental ones. Given the continuum of economic status across socio-economic groups in the U.S., we would not be surprised to witness the steadily increasing concern for economic considerations in many developing countries.

Environmental/conservation concerns date back to the first recitations of the concept of "Public Trust" in English Common Law (Everitt et al. 1980). Public trust precepts simply assert all fish (and wildlife, for that matter) are held in common by all people. In such a context, consumptive and non-consumptive uses of these resources are equally legitimate. As the number and diversity of non-consumptive uses of fish have increased in recent decades, the relevance of these interests to environmental decision-making has also grown. Due largely to their economic well-being, the developed states have witnessed the fastest growth in non-consumptive uses. Given the international influence of these states, their role in promoting national and international bycatch and discard policy is not surprising.

A classic example of the emerging importance of some developed states' attitudes toward the environment and living resources pertains to marine mammals. Although the Roper survey did not investigate U.S. opinions toward marine mammals, Kellert's (1979) review is enlightening. In 1979, issues including DDT and bird survival, leg-hold traps, the Endangered Species Act, the killing of livestock by coyotes, and the Tellico snail darter controversy were major environmental topics. Nevertheless, the issue most widely recognized and opposed by the U.S. public at that time was the commercial and subsistence hunting of harp seals for fur.

Media attention to tuna-dolphin concerns, high seas driftnets, manatees, whale stranding, and sea lion declines has greatly fostered the recognition of marine mammal issues since 1979. Lynge (1992) argues whales (and presumably other marine mammals) have been ascribed a "uniquely special" status by Western cultures that segregate biological life into three bundles: humans, whales and all other biological life. Marine mammal intelligence, social organization,

communication, and presumed "innocence" has broad appeal in many Western societies, but at the same time, such views have formed a fertile ground for the growth of international socio-cultural conflicts. Lynge (1992) raises the relevant question: Are these attitudes toward marine mammals as universal as perceptions suggest? Does Western thought and attitude supersede that of cultures where respect for an animal and the killing of it go hand in hand?

Contrary to perhaps common belief, marine mammals are not viewed equally by every nation. They are hunted for meat in Peru, Chile, Sri Lanka, Greenland, the U.S. (aboriginal harvest), and many other nations (Northridge 1991b). Regardless, most countries would appear to agree it is better not to kill a marine mammal or sea turtle through incidental contact with a net, trawl, or other piece of fishing gear if such contact and mortality can be avoided. Also, it appears to be agreed it is better to avoid discards whenever possible and have national policies which seek to minimize such waste. However, achieving these goals may require some scientifically documented evidence that a real conservation, ecological, or economic problem exists. When significant ideological differences involving the use of resources occur, efforts to recognize and work within the boundaries of such socio-cultural distinctions must be made.

Discard Conflicts Spawned by Socio-Cultural Differences between Developed and Developing Countries

Recognition of cultural differences between developed and developing countries is particularly critical when addressing resource use issues. Much of the developing world encounters conditions differing starkly from those in developed nations. In the U.S., less than 3% of total protein is derived from fish. In contrast, 60% of the remaining world population receives over 40% of its animal protein from fish, and nearly one billion people in Asia depend on fish for their entire supply of protein. Reduction of fish available for consumption in many developing countries would push the average level of protein consumption in these countries into the "deficiency" category. To replace fish with, say, beef protein would require 200 million more beef cattle per year, a quantity in itself associated with obvious environmental consequences (Strand et al. 1992).

Fish also represent a significant source of export earnings for many developing nations. In 1985, fish accounted for at least 20% of export earnings in 21 countries (Strand et al. 1992). Such earnings permitted developing countries to purchase grain, foodstuffs, and other goods and services otherwise unavailable to them.

On a smaller scale, fish are important in many developing nations. In a study of six villages around the Bay of Bengal, 34% of the households in the villages were completely dependent on fishing for their income, while another 25% depended jointly on fishing and fish marketing (*Bay of Bengal News* 1992). Fishing

formed at least part of the household income in 28% of the remaining 41% of the households. Loss of the fisheries on which these villages depend would have dire consequences.

Socio-Cultural Attitudes Toward Discards Based on Different Dependencies on Marine Resources

Although many ideological confrontations associated with bycatch exist between developed and developing countries, a great many consequential disputes related to discards have occurred between developed nations, such as the whaling and driftnet issues. As a result, a more useful paradigm for the analysis of discard concerns inspired by socio-cultural disputes emerges if one considers these disputes in the light of national dependencies on marine resources as a protein staple. Within such a context, discard attitudes of developed nations with a high dependence on marine protein sources are more closely aligned with those of many developing nations than they are with other developed countries for which marine protein sources are less critical components of the national diet.

The cultural ideologies of a nation more heavily dependent upon marine resources as a source of protein for its own population may have positive effects on bycatch management. For one thing, its domestic fisheries may be far less wasteful. The management policies of that nation may clearly reflect an ideology seeking to maximize the long-term protein yield from the entire resource complex. For example, because utilization of the entire complex of harvested species is more balanced, regulations can be adjusted to reduce effort on one component of that complex that is overexploited without sacrificing efficiency in utilization of the entire complex. Short-term attitudes leading to widespread overexploitation and a deterioration of the viability of the protein resource cannot co-exist with such philosophies.

Under such systems, be they in developed or developing countries, bycatch is not wasted. Bycatch is utilized because the nation itself is dependent upon a larger component of the resource complex for its protein needs. Although different fishermen fish different gear types and, of course, have distinctive bycatch discard concerns, conflicts which could emerge from these differences are subjugated for the greater good. Because the community to which the various groups of fishermen belong is directly dependent upon the resource for food, fishermen give way to a cultural ideology that places wise, yet maximum, use benefiting the community as a whole ahead of inter-gear allocation squabbles.

The many island communities of the world are examples of the cultural ideologies heavily dependent upon marine resources for their own domestic consumption. The geography of island communities in many instances has dictated a food culture distinct from what has developed on Asian, European, and American continents. Compared with the early continental inhabitants who relied upon

agriculture and land animals for their food, island communities have turned to animal and plant life from highly productive coastal waters for their main source of protein and vitamins.

The link between the sea and the consumer is much more remote in nations such as the U.S. where fisheries constitute a small component of the food intake. Consequently, social interest in fisheries, if not associated with marine mammals, seabirds, and turtles, has been very slow to develop. Nations with high dependencies on marine resources may look askance at the attitudes of such countries toward marine resource use and management, considering such attitudes wasteful and greedy (Ludwig et al. 1993).

Within-Culture, Social Differences that Drive Discard Conflicts

Clearly, discard problems also offer competing fishers a lever to improve their financial/allocative position in the name of what is right in terms of conservation and the environment. An unfortunate truth of the Olympic fishing system[20] is that all too often the arguments on all sides are at least partially correct and worthy of attention. Intensive trawling operations conducted under the constraint of short seasons induce discard mortalities that might otherwise be avoided if more rational systems were in place. But the same can be said of every other gear type. Thus, addressing the discards in Olympic style fisheries will require close attention to the spectrum of fisheries involved, taking into account fishery-specific discard problems.

How prevalent are similar inter-gear disagreements in the developing world? It appears considerable attention has been given to the development of opportunities for marketing discards, but the role discards play in the allocation of target species is still relatively insignificant. As these fisheries continue to develop and shortages of available resources become more acute, we would expect to see an expansion of this problem. Whether the problem reaches the extent now observed in many developed states may be largely a function of whether or not the developing world moves away from the open-access, free-for-all characteristics of Olympic fisheries prevailing in many of today's developed nations' fisheries.

Development of Discard Policies Recognizing Socio-Cultural Differences

Because of the critical importance of fisheries to many developed and developing nations, the evolution of global bycatch and discard strategies should be designed to minimize social conflicts and, to the degree possible, be independent of

[20] A fishery having a quota, but open to all interested participants thus stimulating a race for available fish.

ideological differences and be based on sound conservation principles. Many of the environmental/conservation programs designed to reduce the catch and discard of marine mammals, turtles, and seabirds have their origins in developed countries. This subset of the world community should be careful to not foist ideological use-based ethics summarily on other nations, be they developed or developing. Instead, if they are sensitive to the socio-cultural and socio-economic circumstances of the developing world in the application of emerging environmental and conservation standards, global acceptance of world bycatch and discard policies will be much more feasible.

The recently signed UNCED agreements and Agenda 21 are excellent examples of instruments of change in our treatment of living ocean resources and the environment. Rather than unilateral pronouncements, these agreements represent months of multi-lateral negotiations attempting to deal with the many rights, beliefs, and obligations of the diverse cultures on this planet. It is hoped this will be more the rule than the exception in our approach to ocean management in the future.

Chapter Summary

Discarding creates a number of problems broadly recognized by the international community. However, stands on ethical issues are not equally appreciated in all countries. Further, solutions to resolve some conservation problems are not fully understood or accepted by various sectors of the world community. Recognition of socio-cultural differences and efforts to bridge current conflict arenas are seen as important to an international effort to promote the reduction in fisheries discarding.

PART III

CASE STUDIES

CHAPTER 5 THE BERING SEA: A MICROCOSM OF GLOBAL BYCATCH ISSUES

Introduction

In 1992, 1.8 million mt of groundfish, 162,000 mt of crab, 2,500 mt of halibut, 35,000 mt of herring, and over 130 million salmon were harvested from the Bering Sea and associated waters. The diversity of resources exploited in the Bering Sea results from a variety of gear types used to target them. Trawl, longline, and pot fisheries pursue groundfish. Crab, halibut, herring, and salmon are taken in pot, line, seine, and net fisheries, respectively. Unfortunately, while each fishery/gear type focuses on the capture of one species or species assemblage, this does not preclude incidental harvest of non-target species, sexes, or size classes. Groundfish fishermen intercept crab, halibut, herring, and salmon. Crabbers encounter groundfish and take large amounts of sublegal male crabs and non-legal females. Salmon fisheries capture species of salmon other than those targeted, as well as groundfish, including halibut.

As with bycatch around the world, these non-target harvests have spawned bitter disputes between fishermen using one gear type or another. For years, such disagreements have led to regulations seeking to protect fisheries resources and the interests of specific fishing sectors.

The Evolution of Bycatch Regulation in the North Pacific

With few commercial fisheries in existence in the North Pacific prior to the 1920s, discarding was not an important management issue at that time. Bycatch was first recognized in the North Pacific in the 1923 United States-Canada Fisheries Halibut Convention. However, even though the Convention recognized the existence of incidental catches of halibut in other fisheries, it did little to discourage their harvest. In fact, the Convention permitted the retention of halibut for use as food for crews. If not so used, the fish were to be turned over to conservation officers when landed (Skud 1977).

Not until after the commercial halibut fishery expanded and the International Fish Commission (IFC, later renamed the International Pacific Halibut Commission) was granted the authority to regulate these fisheries by the 1930 U.S.-Canada Convention did the first of what could be referred to as bycatch regulations

appear. For many years to follow, the majority of all bycatch regulations developed were created with the protection of the halibut resource in mind. Halibut and later salmon and crab took on an elite status, their protection taking precedence over developing fisheries for other species in the region.

In order to reduce the capture of small halibut in the halibut fishery, the IFC closed two halibut nursery grounds (one in Southeast Alaska and one in British Columbia) to directed halibut fishing in 1932. Shortly thereafter (in 1935), dory gear was prohibited in all halibut fisheries south of Cape Spencer, Alaska. Dories, the principal means of setting and retrieving halibut gear in the early stages of the fishery, were thought to selectively harvest small fish (Forrester et al. 1978). For this reason, a complete ban on the use of dories in all convention waters was introduced in 1944 (Myhre 1969).

In recent attempts to rationalize bycatch management in the North Pacific, various managers have suggested the possibility of permitting the retention and sale of prohibited species. In 1937, a regulation resembling the intent of this suggestion was introduced by the IFC into the setline fishery. The so-named "One-in-Seven Rule" allowed one pound of halibut to be retained and sold for every seven pounds of other fish (principally sablefish) harvested during non-halibut openings (Bell 1956). While the program appeared to be a constructive means of dealing with the halibut taken by vessels targeting sablefish, participation in the sablefish line fishery declined as the length of the halibut fishing season increased in the 1960s. In addition, the program was reportedly abused by fishermen who used the "One-in-Seven Rule" regulation to target on halibut illegally. Given these and other problems concerning costs of management and enforcement, the regulation was rescinded in 1966 (Skud 1977).

Although not introduced solely out of concern for bycatch, discards in 1938 the IFC banned the use of setnets in the harvest of halibut in all convention waters (Bell 1956). Studies in the North Atlantic had shown that setnets selected mature, spawning-sized individuals. Because some of these nets had been purchased by West Coast fishermen, the IFC wanted to avoid potential problems in the halibut fishery by restricting their use before they took a foothold in the North Pacific halibut fisheries.

While halibut management was responsible for most bycatch or bycatch-related regulations in the pre-World War II years, other fisheries requiring regulation were beginning to emerge. Trawl gear began to be permitted for use in several fisheries by the mid-1930s. Until 1935, trawls had been banned in the North Pacific, U.S., and Canada with the exception of those used to harvest shrimp. This ban was lifted in 1935 when trawls were permitted in the harvest of flounders as long as such harvest "did not capture, injure, or destroy other food fish" (Fredin 1987).

Domestic king crab fisheries begun in 1936 received their first attention from fishery managers in 1941.[21] Until that time, the concept of bycatch had not existed in these fisheries, since small and softshell crab could be kept by crab fishermen. Restrictions imposed in 1941 did prohibit the retention of small, softshell, and female crabs in the commercial fisheries. Such individuals have been similarly treated in most subsequent crab regulations. A 1952 authorization to retain halibut taken in large mesh nets in Bering Sea crab fisheries was rescinded in 1961 (Knapp et al. 1983). In 1959, legal crab gear was restricted to pots (ADF&G 1991).

Fisheries in the North Pacific after World War II

During the late 1940s and 1950s, a few regulations affecting bycatch were introduced in response to specific concerns, most involving halibut. These regulations prohibiting the use of nets of any kind, included trawls, to harvest halibut (Skud 1977), the retention of halibut taken by bottom trawl gear on an incidental basis (Bell 1956), the harvesting of halibut in certain areas (NPFMC 1983),[22] and a series of early spring sablefish closures considered necessary to reduce incidental halibut catch (Fredin 1987). In addition, the first minimum mesh size limits were introduced in groundfish trawl fisheries in 1948 and crab trawl fisheries in 1952. In 1959, trawls were declared an illegal means of harvesting crab--presumably because of gear conflicts and the capture of sublegal sized crabs (NPFMC 1983).

Bycatch regulations as a means of fishery management became increasingly important in the 1960s as U.S. managers attempted to control the large foreign trawl fisheries in the Bering Sea and Gulf of Alaska. Previous measures, mostly confined to U.S. and Canadian fishermen, had taken up but a few pages in the regulations of the IFC (now IPHC) and U.S. Bureau of Commercial Fisheries.[23] In the 1960s, bycatch regulations quickly grew in complexity as they attempted to protect the interests of U.S. and Canadian fishermen.

Most of the regulations introduced in the 1960s and 1970s were designed to protect the Pacific halibut resource or to minimize conflicts between foreign fisheries and U.S. pot and other fisheries. As early as 1959, the Japanese government voluntarily closed an area on the north side of the Alaska Peninsula to its trawl fleets in an effort to minimize the capture of crab important to U.S. fishermen in the area (Fredin 1987). In 1963, the Japanese entered the Gulf of Alaska groundfish fisheries, but restricted their vessel operations to specific areas

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[21] Tanner crab regulations were first imposed in 1967.

[22] In 1948, the IFC prohibited the use of otter trawls in areas populated by small halibut and in areas closed to directed halibut fisheries.

[23] The U.S. Bureau of Commercial Fisheries was later transferred to the Department of Commerce and was renamed the National Marine Fisheries Service (NMFS).

because of U.S. concern over the effect of these fisheries' bycatch mortalities on the halibut fisheries (Fredin 1987; USFWS 1964).

In 1963, the first fishery observers were used in North Pacific fisheries. These observers, originating from the United States and the IPHC, were placed onboard Japanese trawlers in the Gulf of Alaska in order to monitor halibut discards (Forrester et al. 1978). Since 1963, fishery observers have played an integral role in collecting the biological information necessary to understand the level of bycatch and discards and their impacts on non-target fisheries.

Beginning in 1964, a series of bilateral agreements between the U.S. and Japan and between the U.S. and the Soviets became the basis for fishing and bycatch management in the North Pacific. Time and area bans, as well as gear prohibitions, increasingly restricted distant water operations in the region. Milestones included the elimination of the tanglenet fisheries in 1973, the first regulations associated with marine mammal bycatch, and the imposition of a pot sanctuary and late winter and early spring trawl closures in the Bering Sea.

Bycatch management became even more volatile in the region after the passage of the Fishery Conservation and Management Act (FCMA) by the U.S. Congress in 1976. Bycatch management prior to passage of the Act was primarily a function of negotiating catch and bycatch concessions from foreign fishermen. Following passage of the Act, as the catch and bycatch needs of U.S. fishermen increased, many of the protective regulations designed to control bycatch levels in foreign fisheries were simply transferred from foreign interests to developing U.S. groundfisheries. Groundfish harvests by U.S. interests grew from almost zero following passage of the FCMA to close to two million mt a decade and a half later. Meanwhile, bycatch regulations progressed rapidly from simple instructions to try to avoid or minimize the capture of selected species, to caps limiting the total removal of prohibited species, eventually to the present system combining caps with time/area closures and various other management controls. The process moved quickly from the reassignment of catch and bycatch from distant water fleets to U.S. fleets and ultimately led to the heated debates between U.S. fishermen observed today.

The North Pacific Fishery Management Council (NPFMC), the entity responsible for managing the groundfish resources of the U.S. in the Northeast Pacific region, which shares authority with the Alaska Department of Fish and Game for crab issues and the International Pacific Halibut Commission for halibut, has been embroiled in recent years in disputes involving bycatch issues. A series of groundfish management plan amendments[24] limited the takes of crab, halibut, salmon, and herring (*Clupea pallasi*) in the groundfish fisheries and allocated these incidental harvest quotas among gear types in the groundfish fishery. Mortality

[24] The North Pacific Fishery Management Council developed the concept of "prohibited species." Selected species from the traditional domestic fisheries were listed as prohibited from capture and retention by the developing groundfisheries of the region.

rates of discards continue to be a source of debate. All in all, it is likely millions of dollars and thousands of hours have been spent on management questions associated with discard in the region.

Bering Sea Bycatch and Discard Statistics

Throughout the 1980s, as bycatch regulations were developed, revised, and reissued for domestic fishermen in the Bering Sea, one fact continued to be recognized--better discard catch data were needed. In order to improve fishery management, protect the stocks, and ensure the commercial viability of all fisheries in the region, information concerning bycatch in each of the fisheries was considered particularly relevant. During the transitional period in the mid-1980s when U.S. fishermen began to replace the large-scale distant water fisheries of foreign nationals which had 100% observer coverage, only spotty target and non-target catch data were recorded for the growing U.S. fleet. Reduced observer coverage made it difficult for management entities to evaluate impacts of non-target mortalities, be they on fish or fisheries.

This situation changed in 1990 when observer coverage was mandated on groundfish vessels operating in the Bering Sea and Gulf of Alaska. Vessels greater than 125' overall were required to carry a biological observer 100% of the time. Thirty percent of the effort of boats smaller than 125' and larger than 60' was to be monitored. Shoreside processing plants were also faced with observer coverage requirements of varying levels. Observers were required to have academic backgrounds in fisheries or related biological sciences and underwent training courses conducted by the U.S. National Marine Fisheries Service. Potential observers were hired by independent observer contractors. Individual vessels or fishing companies contracted with the companies for observers and paid them directly at rates ranging from $3,500 to $5,000 per month per observer.

The observer program addressed many of the information concerns prevailing before the program began. Large amounts of data on target and non-target catch volumes in the target fishery have been collected. Unit weights and lengths, sexual maturity, and other data necessary for determining the biological characteristics of individuals taken and discarded in the fishery are now available. Important discard data are accessible in near-real time. Consequently, the resulting information can be used for short-term fishery management decisions, a capability of ever-increasing importance, given the overcapitalized and Olympic nature of the Alaskan groundfish fisheries. Such decisions include the identification of bycatch "hot-spots" for vessels to avoid, bycatch quota management on a week-to-week basis, and vessel-specific incentive/enforcement plans.

Of course, the data of greatest relevance to our interests in this study are those offering insights into the bycatch volumes and rates of discards occurring in the region. Although many of the gear types in operation around the world are

deployed in the Bering Sea, the extensive datasets available for the region may shed light on the potential level of discard rates associated with similar fishery/gear type combinations in existence in other fishing regions of the globe.[25]

At the time of this writing, the most current full year for which data are available from the Bering Sea observer program is 1992. Table 21 documents total retained and discarded weight and number for four gear types and nine target fisheries in the Bering Sea. Discard rates on a weight per weight and number per number basis are also presented. Discard values include all species, sizes, and sexes, and so-called "prohibited species," such as salmon, herring, and halibut. Likewise, retained catch includes all landed target and non-target species.

Table 21. Total retained and discarded weight and number for four gear types and nine target fisheries in the Bering Sea.

Gear	Target	Discarded Weight (mt)	Discarded Number	Retained Weight (mt)	Retained Number	Discard Weight per Weight	Discard Number per Number
Line	Cod	19,700	20,141,857	90,273	26,656,727	0.22	0.76
	Sablefish	819	1,540,070	2,119	689,297	0.39	2.23
	Turbot	26	49,961	73	25,691	0.36	1.94
Jig	Cod	7	17,336	1	192	9.85	90.29
Pot	Cod	215	702,593	13,205	3,838,416	0.02	0.18
	Sablefish	1	2,312	1	146	2.20	15.84
Trawl	Atka mackerel	6,691	13,998,929	42,342	53,925,476	0.16	0.26
	**>20% Pollock	29,300	111,367,796	138,882	170,243,467	0.21	0.65
	Cod	23,779	80,874,227	42,189	17,971,591	0.56	4.50
	Rockfish	3,774	10,026,051	12,574	20,494,278	0.30	0.49
	**>95% pollock	40,651	120,243,881	1,043,800	1,318,636,387	0.04	0.09
	Rock sole	29,481	201,256,455	20,571	47,314,112	1.43	4.25
	Sablefish	2	4,614	28	8,150	0.07	0.57
	Yellowfin sole	56,638	353,797,480	101,001	304,743,648	0.56	1.16
Totals		211,084	914,023,562	1,507,058*	1,964,547,578	0.14	0.47

*Portion of the 1992 NMFS reported catch, over 1.7 million mt, includes discarded pollock, cod, and sablefish.
**Greater than 20% pollock and greater than 95% pollock are not target fisheries, but catch composition delineations. A variety of different target fisheries may be involved in the bycatch, particularly for the >20% pollock grouping.

[25] Discards in the Eastern Bering Sea today cannot be easily compared with other similar fisheries around the world where cultural values have a stronger influence upon utilization. Furthermore, current levels of discard rates for the U.S. fishery in the Eastern Bering Sea cannot be assumed representative for all fisheries and gear types which have operated in the region. The foreign fisheries before and after establishment of the U.S. EEZ utilized the resources more efficiently, even though some of the bycatch had to be discarded.

Important contributors to the regional total discard weight include the cod, pollock, and yellowfin sole trawl fisheries accounting for 11%, 33%, and 27% of regional bycatch weights, respectively. These same three fisheries accounted for 71% and 64% of total discard weight and numbers in 1992.

On a weight basis, the cod jig, sablefish pot, and rock sole trawl fisheries all discard more tonnage and numbers of fish than they retain, but the cod jig and sablefish pot fisheries are very small and contribute little to total regional discards. The rock sole fishery accounts for 15% of total Bering Sea discard weight and 23% of discard number, even though the fishery itself lands only a little over 1% of the regional groundfish total. Discard numbers from the sablefish line, turbot (*Atheresthes stomias*) line, cod trawl, and yellowfin sole (*Limanda aspera*) trawl also exceed retained numbers. Discarded weight for these fisheries is considerably less than retained weight, since their bycatch consists of high numbers of small individuals.

Low weight-based discard rates were identified for the pot cod (2%), >95% pollock trawl (4%), and sablefish trawl (7%) fisheries. The >95% pollock trawl operation is a major fishery responsible for more than two-thirds of all groundfish landings. Nevertheless, its low bycatch rate produced total discards only 19% of the regional discard weight and 13% of the regional discard number in 1992. Conversely, the >20% pollock trawl classification, although responsible for only 12% of total pollock harvests, accounts for nearly 42% of all discards generated by the two pollock categories. NMFS data can also differentiate between on-bottom and pelagic fisheries for pollock. When this is done, the quantity of non-pollock discarded from the pelagic fishery represents just 0.06% of the total catch.[26]

The discards recorded for each fishery include sublegal or undersized target species, as well as non-target individuals. In the pollock categories, for example, pollock alone account for about 60% to 70% of total discards. Sizable amounts of discards of Pacific cod, rock sole, arrowtooth flounder, and other flounders also occur in the pollock fishery. When these and other species are added to the mix, total discards in the pollock grouping rise to roughly 70,000 mt in conjunction with the 1.18 million mt retained harvest of pollock.

Like the pollock fishery, Atka mackerel (*Pleurogrammus monopterygius*) discards represent approximately 60% of total discards in the Atka mackerel fishery. The situation is, however, quite different for harvests of other species by trawl gears and harvests by other gear types. Discards of small cod in the cod trawl fishery totaled 2,165 mt in 1992. If discards of pollock, rock sole, arrowtooth flounder, Atka mackerel, and other species are added to this total, discards mount to 23,779 mt, more than ten times higher than cod discards alone. Yellowfin sole, rockfish, and rock sole discards account for 44%, 20%, and 32% of total discards

[26] Discards of small pollock are not delineated with this breakout.

in their respective trawl fisheries. In the line fisheries, cod account for 1% of total cod line discards while sablefish are responsible for 0.1% of all sablefish line discards. Halibut is a key contributor, comprising approximately 30%, to the cod line discards. In the sablefish fishery, various flounders and skates account for more than 60% of the non-sablefish discards.

Several species are harvested by more than a single gear type in the Bering Sea. In these cases it is interesting to look at how discard rates vary across the targets. Cod taken in line, pot, jig, and trawl operations offers a good basis of comparison. Discard rates (by weight) associated with the harvest of cod range from 9.85 for the tiny cod jig fishery to 0.56 in the trawl fishery, 0.21 in the line fishery, and 0.02 in cod pot operations. Thus, more than two orders of magnitude difference in discard rates occur between gear types targeting on the same species.

Similar variations can be observed in discard rates across the range of other species harvested and gear types used in the Bering Sea. Table 21 demonstrates that no single major gear type in use in the region has consistently high or low discard rates. Trawl rates range from 0.04 to 1.43, with an average of 0.41 kg discarded per kg retained. The weighted mean discard rate (weighted by the retained tonnage of each trawl fishery) for trawl operations in the Bering Sea drops to 0.15 kg/kg owing to the high retained tonnage and low discard weight in the pelagic pollock trawl fishery. Longline rates show the least variance, rising from a low of 0.22 kg/kg in the cod line fishery to a high of 0.39 kg/kg in the sablefish fishery. The weighted mean discard rate for line gear is 0.22 kg/kg, somewhat higher than in the trawl fishery. Pot fisheries, meanwhile, show the greatest range in discard rates, varying by more than two orders of magnitude between the low cod and high sablefish pot discard levels.

The quantities of each target species retained and discarded in 1992 by all trawl and line gears in the Bering Sea are provided in Tables 22 and 23. The tables include discards of prohibited species of halibut and herring. For the Bering Sea trawl fisheries, the retained catch weight amounted to 1,341,440 mt and the discarded catch weight 204,491 mt. Additional catches in numbers are shown for crab and salmon.

Table 22. Catches and discards (mt) of all groundfish species in the Bering Sea/Aleutian Islands trawl fisheries during 1992. Source: NMFS Special Data Run, Alaska Fisheries Science Center, Seattle.

Species	Retained Catch (mt)	Discarded Catch (mt)	Discard/Retained Ratio (%)
Pollock	1,115,730	75,734	0.07
Sablefish	70	5	0.07
Atka mackerel	39,670	6,453	0.16
Pacific cod	57,977	11,265	0.19
Pacific Ocean perch	10,559	2,218	0.21
Yellowfin sole	90,885	31,252	0.31
Flounder	5,044	24,007	0.48
Turbot	317	223	0.70
Rocksole	18,591	21,829	117.00
Other	1,980	14,664	741.00
Rockfish	78	631	810.00
Arrowtooth flounder	539	6,738	1,250.00
Halibut	0	5,136	
TOTAL GROUNDFISH	1,341,440	204,491	0.15
OTHER			
Herring	0	4,386	
Salmon (number)	0	3,695,940	
Tanner crab (number)	0	145,344	
King crab (number)	0	38,108	

Discard rates for Bering Sea crab fisheries observed during 1991 and 1992 are provided in Table 24. The number of individuals discarded per retained male is relatively high for king crab, exceeding 7.2 per retained male for golden king crab caught near Dutch Harbor and nearly six discards per retained male in the Bristol Bay red king crab fishery in 1992. Reeves (1993) estimates that in 1992 over 16,000,000 red king crab were discarded in the crab pot fisheries.

Table 23. Catches and discards (mt) of all species in all Bering Sea/Aleutian Islands hook-and-line fisheries during 1992.
Source: NMFS Special Data Run, Alaska Fisheries Science Center, Seattle.

Species	Retained Catch (mt)	Discarded Catch (mt)	Discard/Retained Ratio (%)
Pacific cod	89,607	283	0.01
Sablefish	1,885	20	0.01
Rockfish	295	61	0.21
Yellowfin sole	0	67	100.00
Atka mackerel	19	23	121.00
Turbot	294	780	265.00
Rocksole	9	323	356.00
Other	938	8,131	867.00
Pacific Ocean perch	7	81	1,157.00
Flounder		244	2,030.00
Arrowtooth flounder		1,336	2,470.00
Pollock	73	2,558	3,504.00
Halibut	0	6,958	
TOTAL GROUNDFISH	93,190	20,572	0.22
OTHER			
Salmon (number)	0	148	
Tanner crab (number)	0	18,955	
King crab (number)	0	2,425	

Table 24. Discard ratio for Bering Sea crab fisheries, 1990, 1991 and 1992.
Source: Reeves 1993, Tracy 1993, and Beers 1992.

Year	Species/Fishery	Number Discarded per Number Retained
1990	Adak golden king crab	5.126
1990	Dutch Harbor golden king crab	9.948
1991	Dutch Harbor golden king crab	7.23
1991	Bering Sea snow crab	0.106
1991	Bering Sea Tanner crab	0.895
1991	Bristol Bay red king crab	1.583
1991	St. Matthew blue king crab	2.036
1992	Bristol Bay red king crab	5.889

Discard Impacts on Stock Dynamics

A closer look at some of the specific fisheries generating bycatch within the Bering Sea presents some interesting results. If discard rates recorded in the 1992 pollock fishery had held for earlier years,[27] pollock discards in the pollock fishery could have ranged from 88,000 to 130,000 mt and from 140 million to more than 350 million individuals annually over the last 15 years. During this period, the pollock fishery in the Eastern Bering Sea has yielded annual harvests in excess of 1 million mt since 1984 and greater than 900,000 mt since 1970. Particularly large harvests in excess of 1.5 million mt occurred in the early 1970s with the recent peak of 1.35 million mt taking place in 1990. In the face of these discard and landing values, stock biomass rose from 4.3 million mt in 1979 to 9 million mt in 1985 before stabilizing in the range of 6 to 8 million mt in recent years (Quinn and Collie 1990).

Although pollock discards have reached as high as 350 million individuals and 130,000 mt during the last 15 years, discards, on average, represent less than 1% of the exploitable pollock biomass in most years.[28] Although the numbers of pollock discards are high, the effort is negligible when compared with mortalities from other sources.

The estimated 1992 mortalities resulting from discarding major commercial target species in the Bering Sea is provided in Table 25. The annual mortality attributed to pollock discards is 0.016,[29] about 10% of the annual mortality due to landings. The increase in total instantaneous mortality (z) resulting from discards is less than .01. Discard-induced mortalities for cod, Atka mackerel, sablefish, and Pacific Ocean perch are also relatively small in relation to mortalities resulting from landings of these species, and the increase in total instantaneous mortality is substantially less than one for each of these species.

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[27] We recognize the actual rates will vary sharply, depending on the recruitment and the numbers and weight of animals in the exploitable population.

[28] A high of 1.6% was reached in 1992.

[29] Assumes 100% mortality for discards.

Table 25. Estimated fishing mortality rates for key species in the Bering Sea in 1992 resulting from discarding major commercial target species (assumes 100% mortality of discards).
Source: NRC and the NMFS Alaska Fisheries Science Center 1992.

Species	Mortality Due to Discards	Mortality Due to Landings
Pollock	0.016	0.171
Pacific cod	0.013	0.190
Atka mackerel	0.008	0.053
Rockfish	0.004	0.008
Yellowfin sole	0.012	0.046
Sablefish	0.001	0.053
Greenland turbot/ Arrowtooth flounder	0.012	0.014
Rock sole	0.015	0.027
Flounder	0.020	0.024
POP	0.005	0.035

In several cases, however, discard mortalities are sizable compared to landings mortalities. Annual mortality due to discards of turbot/arrowtooth flounder and the flounder group nearly matches landings. The rock sole and rockfish discard mortality rate is one-half of the respective landings mortality rate. The yellowfin sole annual discard mortality rate of 0.012 is one-quarter of the annual landings mortality figure. However, for each of the above species, the combined fishery discard and landing mortality rates are far below what are required to achieve the authorized Allowable Biological Catch (ABC).

Managers use a variety of techniques to adjust for the consequences of discard mortalities, and it is noted that for several species in the Bering Sea and Gulf of Alaska the losses due to discards are deducted from authorized catches. It is also apparent in the development of resource management plans that when such losses are known they are accounted for in relevant authorized catches. In the Northeast Pacific, the IPHC-approved method for adjusting the halibut stock for bycatch losses (discard mortalities) is to reduce harvest in the directed line fishery "such that the reproductive potential of the exploitable component of the stock would be the same after bycatch as it would have been if bycatch had not occurred" (Sullivan et al. 1993). According to Trumble et al. (1993), if reproductive compensation is done correctly, and if bycatch mortality is estimated correctly the halibut spawning stock should remain the same. The directed fishery pays for maintenance of the catch through the reduced quota.

Unlike many of the groundfish fisheries, the king crab fishery is an instance where discards may have done much to shape current stock conditions. King crab discard numbers in the crab fisheries as a percentage of estimated population

numbers range from 20% to 40% in most years since 1980 and approach 80% in some years. Even at a low mortality rate of 25% for the discarded sublegal and female individuals, these discard levels could confront the king crab stocks in the region with substantial additional mortalities (Reeves 1993)--and this is without considering the losses associated with crab bycatch in the trawl fisheries (Table 26). It is perhaps not surprising king crab fisheries have struggled to reach 10 million lb of landings since their 1981 collapse from annual harvests in excess of 100 million lb.

Table 26. Estimated king crab population, discard as a percentage of population size (number landed per number landed), and discard mortality as a percentage of population size, 1980-1991. Based on 50% discard mortality. Source: NPFMC 1991, and Reeves 1993.

Year	Population (number)	Discard Percent (number to number)	Discard Mortality Rate
1980	229,300,000	82.97%	41.49%
1981	189,900,000	32.34%	16.17%
1982	261,300,000	4.61%	2.31%
1983	89,200,000	4.10%	2.05%
1984	172,700,000	2.04%	1.02%
1985	39,900,000	9.57%	4.79%
1986	39,900,000	22.10%	11.05%
1987	75,700,000	11.78%	5.89%
1988	39,700,000	13.91%	6.96%
1989	51,100,000	15.95%	7.98%
1990	52,200,000	32.70%	16.35%
1991	43,900,000	39.16%	19.58%

Using recent data collected in the on-board crab observer program in the Bering Sea, Reeves (1993) confirms earlier work by Alverson (1980) which had identified the benefits of smaller minimum size limits in the king crab fishery. Lower minimum sizes would permit retention of many individuals which might die if discarded. It is important to note that there are no solid data on discard mortality levels and the levels used in Table 26 cannot be verified. Regardless, catch quotas represent an important but incomplete fraction of crab mortality in the crab fisheries.

Tables 22 and 23 provide data on the catch and discard of salmon from the bottom fisheries in the Bering Sea region. Erickson and Pikitch (in press) have also studied the capture and discard of chinook salmon in fisheries along the West Coast of the U.S. (California, Oregon and Washington). They report a chinook salmon

catch of 7,761 for 1987, or approximately 1.4% of those years' commercial ocean landings (troll gear). Although salmon bycatch has been reasonably well documented for trawl fisheries (NRC 1990), it is perhaps less evident that seine, hook and line, and gillnet salmon fisheries have their own bycatch problems.

Other than data associated with trawling, NRC was unable to locate bycatch discard data for the Bering Sea salmon fisheries. In waters to the south of the Bering Sea, the incidental catch of juvenile chinook salmon in the Puget Sound purse seine fishery (Area 7/7A) between 1976 and 1985 varied from 111% to 489% of the adult chinook catch in this fishery, but the number of juveniles as a fraction of all target salmon species catch in numbers was much lower (0.57% to 4.39%). The situation in Puget Sound areas 8-13 regarding juvenile discards was much worse, ranging from 434% to 2867% of adult salmon catch (Shepard 1994). Riddel and Fraidenburg (1987) estimate the unobserved bycatch of chinook salmon, as a function of legal harvest numbers taken in West Coast and Alaska salmon purse seine fisheries from 1977 to 1985 (Table 27):

Southeast Alaska	155.3%
Northern British Columbia	75.4% to 135%
Vancouver Island	292% to 411%
Georgia Strait	19.1% to 107.4%
Puget Sound	250% to 290.1%

Again, these numbers constitute bycatch as a function of the chinook legal harvest, not of the overall salmon catch which is much lower.

Table 27. Incidental mortality (number of fish) of chinook salmon in West Coast and Alaska salmon purse seine fisheries. Source: Riddel and Fraidenburg 1987.

AREA	PERIOD	SUBLEGAL	LEGAL RELEASED	ESTIMATED UNOBSERVED BYCATCH	TOTAL INCIDENTL CATCH NUMBERS	PERCENTAGE OF LEGAL HARVEST NUMBERS
Southeast Alaska	1977-1982	NA	18,206	10,100	28,306	155.30%
Northern British Columbia	1977-1982	NA	NA	33,100	33,100	75.4%
	1983/1984	NA	NA	22,400	22,400	100.00%
	1985/1986	NA	NA	36,700	36,700	135.67%
Vancouver Island	1977-1982	NA	NA	31,300	31,300	292.52%
	1983/1984	NA	NA	11,100	11,100	411.11%
	1985/1986	NA	NA	34,085	34,085	261.79%
Georgia Strait	1977-1982	NA	NA	16,700	16,700	52.85%
	1983/1984	NA	NA	21,900	21,900	107.35%
	1985/1986	NA	NA	4,800	4,800	19.05%
Puget Sound	1977-1982	146,480	NA	NA	146,480	290.06%
	1983/1984	102,520	NA	NA	102,520	250.05%
	1985/1986	101,510	NA	NA	101,510	285.94%

For troll salmon fisheries, Riddel and Fraidenburg (1987) report estimates of unobserved bycatch of 25% to 69.2% of legal harvest numbers, depending on area and year observed. Most of the discarded salmon were sublegals. Sports fishermen records were not much better and produced an estimate of incidental mortality associated with legal harvest numbers of 29.6% to 102.6% in British Columbia waters.

Although the bycatch of chinook salmon is obviously relatively low when considering the take of all salmon by these fisheries, the numbers nevertheless demonstrate the severity of the problem confronting managers dealing with this mixed species fishery. We have noted only some of the observed rates of bycatch for chinook, involving only species of salmon, but similar efforts may occur in other minor stocks, such as coho and steelhead, in particular river systems Furthermore, the bycatch of other fish species and birds is a problem in some areas. The gillnet catches of steelhead on the Skiena River, British Columbia, Canada, are the basis for a confrontation between sport and commercial fishermen. Similarly, harvesting pink salmon (*Oncorhynchus gorbuscha)* can in some locations have harmful effects on coho, chum (*Oncorhynchus keta*), and sockeye (*Oncorhynchus nerka)* salmon fisheries. In many of the above cases, however, the problem is dealing with mixed stocks as a bycatch issue, but often not as a discard issue (Larkin, pers. comm.). The extent of impacts and management conflicts resulting from bycatch in salmon fisheries in the Bering Sea are unknown, but given what has been observed in other areas is undoubtedly a part of the pervasive nature of the overall bycatch issue.

Species Diversity in the Bering Sea Fisheries

In most Bering Sea fisheries, the bulk of the catch is comprised of a relatively low number of species. Nevertheless, it is also true that in most of the fisheries, the dominant species are frequently accompanied by dozens of other species. While contributing little to catch weight or numbers, these other species expand the diversity of the harvest tremendously and provide considerable data concerning the overall species assemblage of the region.

Table 28 documents the number of different species taken in the various target fisheries in the Bering Sea during 1992 and presents Simpson's diversity index (Elseth and Baumgardner 1981) and Caddy's (1989) index of gear selectivity. The number of species taken in line, pot, pelagic trawl, and bottom trawl fisheries ranges from a low of twelve in the Atka mackerel pelagic trawl and arrowtooth flounder pot fisheries to a high of 119 in the pollock pelagic trawl fishery. On a gear-specific basis, pot gear intercepts the lowest mean number of species (29) but also exhibits the greatest amount of variation around that mean (SE = 15, n = 3). Conversely, non-pelagic trawl gear takes the highest mean number of species (81), but the data used to compute this mean show lower variability than for any other gear type. With the exception of the turbot bottom trawl fishery, the number of

species taken by non-pelagic trawl ranges from a low of 72 to a high of 112. This range is much tighter than the spread from 34 to 108 species noted for line gears and the 12 to 119 noted for the pelagic trawls.

Table 28. Different species taken in major commercial fisheries in the Bering Sea along with Caddy's Index and Simpson's Diversity Indices.

Fishery	Gear Type	Number of Species	Caddy's Index	Simpson's Diversity Index
Rockfish	Line	34	0.029	0.909
Sablefish	Line	36	0.028	0.702
Arrowtooth flounder	Line	38	0.026	0.807
Turbot	Line	42	0.024	0.568
Pacific cod	Line	108	0.009	0.352
Turbot	Non-pelagic trawl	26	0.038	0.539
Arrowtooth flounder	Non-pelagic trawl	72	0.014	0.821
Atka mackerel	Non-pelagic trawl	75	0.013	0.211
Rock sole	Non-pelagic trawl	76	0.013	0.645
Rockfish	Non-pelagic trawl	84	0.012	0.643
Pollock	Non-pelagic trawl	102	0.010	0.458
Pacific cod	Non-pelagic trawl	104	0.010	0.456
Flatfish	Non-pelagic trawl	112	0.009	0.537
Atka mackerel	Pelagic trawl	12	0.083	0.251
Rockfish	Pelagic trawl	14	0.071	0.677
Rock sole	Pelagic trawl	30	0.033	0.691
Arrowtooth flounder	Pelagic trawl	34	0.029	0.699
Flatfish	Pelagic trawl	35	0.029	0.793
Pacific cod	Pelagic trawl	38	0.026	0.270
Pollock	Pelagic trawl	119	0.008	0.022
Arrowtooth flounder	Pot	12	0.083	0.756
Turbot	Pot	16	0.063	0.364
Pacific cod	Pot	59	0.017	0.116

Gear Type	# of Species Mean	Caddy Index Mean	Simpson Index Mean
Line	51.6	0.023	0.668
Non-pelagic trawl	81.4	0.015	0.539
Pelagic trawl	40.3	0.066	0.486
Pot	29.0	0.054	0.412

The high number of species intercepted by bottom trawls is not surprising. Bottom trawls at times capture species living in the sediments, fixed to the sediments (for example, corals, sponges), and epibenthic forms, as well as a variety of near-bottom fishes and invertebrates. By comparison, pelagic trawls, when fished off bottom, generally avoid contact with most bottom or near-bottom organisms. The exception seems to occur when targeting pollock with pelagic gear, perhaps indicating occasional net contact with the bottom.

Caddy derived an index of gear selectivity (I = 1/S where S is the number of species taken by a gear type) to investigate the selectivity characteristics of fisheries operating in the British Virgin Islands (BVI) (Caddy 1989). His values ranged from a low of 0.03 in the fish trap fishery to a high of 1 in the jig fishery. Values approaching 1 indicated increasing gear selectivity, that is, if a gear took only one species, its index value would equal 1, whereas if it took ten species, its index would equal 0.10. Because the indices were derived only from landings of commercially important species and ignore discarded species, Caddy suggests the values observed overestimate the true selectivity of the gear.

Data from the Bering Sea fishery support Caddy's hypothesis. Bering Sea values reach a high of 0.083 for a pot fishery, compared to a BVI jig fishery with its value of 1, and fall to a low of 0.008 and 0.009 in the pollock pelagic trawl and flatfish bottom trawl fishery, respectively. Most BVI values calculated by Caddy are much higher than Bering Sea figures.

Longline and pot gear were used in both areas. Bering Sea longline fisheries intercept from 34 to 108 species, for a mean selectivity of 0.023, compared to the seven species, with a selectivity of 0.14, landed by longline operations in the BVI. An interesting exception to the rule of lower Bering Sea and higher BVI selectivity indices involves the pot/trap fisheries. The BVI fish trap value is actually lower than most of the index values for Bering Sea fish pot fisheries. This probably reflects there is a greater species diversity in the tropical fishery or perhaps a large number of the fish taken in BVI traps are landed and thus subject to study.

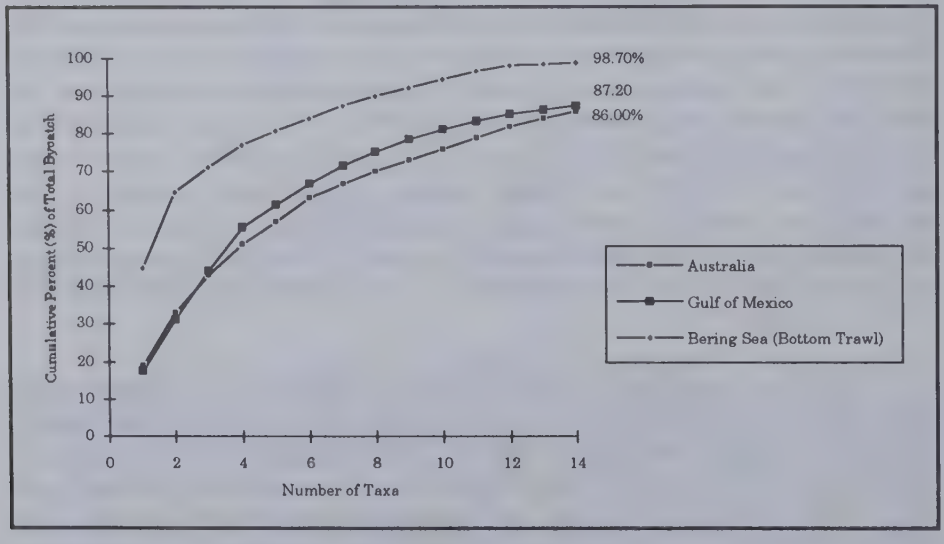
Counts of the number of species taken in a gear provide valuable information on the species selectivity of one gear type compared to another. But species counts say nothing about the relative abundance of each species in the catch. For example, if a gear type catches twenty incidental species, but catches only one individual of each species, does this mean it is more selective then a gear type that takes only one additional species, but at a number equal to the non-target species? Use of Simpson's diversity index ($C = 1 - \sum p_i^2$, where p_i is the proportion of each species in the catch) provides a different measure of the diversity characteristics for the Bering Sea fisheries. If many species of equal abundance are taken in a fishery, the diversity index within that fishery will approach 1. As fewer species are taken or if a small number of species account for a high proportion of the take, then diversity will fall.

Simpson's diversity index measurements for the Bering Sea fisheries range from 0.02 in the pollock pelagic trawl to 0.91 in the rockfish line fishery. Although the pelagic trawl fisheries take and discard a large number of species, the overall catch of the target species is very high while the quantity of discards is very low. In the trawl rockfish fishery, several species of rockfish are targeted. This strategy lends itself to a more even distribution of the catch among different species and a higher diversity value than for fisheries where a single species is targeted.

Results of the diversity analysis suggest conclusions about species diversity by gear types can be better understood using a combination of the Caddy and Simpson diversity indices. In the Bering Sea, pot fisheries intercepted, on average, far fewer species than did the bottom trawl fisheries (29 vs. 81). Nevertheless, the Simpson diversity index for the bottom trawl fishery is only slightly above that for the pot fishery and is actually lower than the value derived for the line fisheries. Thus, while bycatch and discards in the bottom trawl fishery may affect a broader component of species in the Bering Sea than pot and line gears, many of the species discarded from the trawl fishery account for only a very small fraction of the total discards and thus have little impact on the diversity index value. Conversely, in the line fisheries the catch is more evenly distributed across species and diversity values rise accordingly. This occurs despite the fact the numbers of species taken in the line gear are lower than in the non-pelagic trawl.

In comparing the numbers of species/families of fishes taken and the distribution of mass among species for the Bering Sea trawl fishery and similar data from tropical shrimp trawl fisheries, it becomes readily apparent that distribution of the catch (by weight) for bycatch species in the tropical shrimp fisheries spreads out over many more species. In the Bering Sea pollock fishery, 14 species comprised 98.9% of the discard catch (by weight). By comparison, in the Australian northern prawn fishery and the Gulf of Mexico shrimp fisheries 14 families (many species) comprised only 86.5% of the discard catch (Table 29).

Table 29. Cumulative percent of top fourteen bycatch taxa by region. Source: NRC data files.



Chapter Summary

Bycatch regulation in the Northeast Pacific region began early in the century and largely involved efforts to minimize bycatch mortalities imposed by non-line fisheries on halibut. Following World War II, a rapid expansion of distant water fisheries occurred in the Bering Sea and Gulf of Alaska. These new fisheries were seen as a threat to U.S. and Canadian traditional salmon and halibut fisheries, and a number of bycatch agreements were established among the U.S., Canada, and other nations whose fleets fished off northwest North America. These agreements provided for the protection of (a) juvenile halibut grounds and (b) areas where U.S. fishermen traditionally fished crabs. In addition, the agreements led to an international observer program for distant water fishing vessels. U.S. groundfish fisheries expanded rapidly in the late 1980s, and a broad-based observer program for U.S. vessels was established early in 1990. The program has resulted in the development of a comprehensive dataset documenting discard levels for all groundfisheries of the region.

The Northeast Pacific discard data show current discard levels are relatively low for most species, although relatively high discard mortality is noted for halibut and a potentially significant problem may exist in the crab fisheries of the region. Impacts at the population level are relatively small for most species of groundfish, although altogether the total number discarded are estimated to exceed one billion annually.

Multi-species management options should examine selectivity and diversity measurements derived from discard and retained catch data. Values obtained through landings alone will mis-characterize the community effects of fishing in most instances.

CHAPTER 6 THE NORTHWEST ATLANTIC

Introduction

In this chapter, an overview of bycatch and discard issues for some U.S. fisheries in the Northwest Atlantic is provided, with emphasis on results from quantitative stock assessments that have included discard estimates. Management efforts aimed at reducing bycatch and discards are considered. Finally, a brief review of information on the impacts of discards on some common stock assessment calculations is provided.

The Nature of Bycatch and Discards

Fisheries in the Northwest Atlantic are generally well developed, and most resources are either fully exploited or overexploited. The diversity of directed fisheries results in a high degree of interaction among fisheries. Bycatch, as elsewhere, presents both problems and opportunities for the fisheries of the Northwest Atlantic. The fact the region's resources are so highly mixed and diverse has resulted in very few fisheries truly focused on single-species targets. As an example, even for the dredge fishery for scallops, finfish bycatch of species, such as summer (*Paralichthys dentatus*) and yellowtail flounders (*Limanda ferruginea*) and monkfish, makes up important economic elements of the unsorted catch. With the recent decline in scallop populations, revenue from the finfish bycatch from this fishery--once sold for cash by the crew as "shack landings"--has come to represent an important overall source of vessel income. Likewise, in years when highly valued species, such as haddock, cod, and yellowtail flounder, were abundant, trawl tow times were short and directed fisheries generated catches yielding high proportions of these target species.

The significant decline in traditional groundfish species over the last decade (NOAA/NMFS 1993) has resulted in much less species-specificity in targeting. One consequence of the decline in groundfish is longer tow times in trawl fisheries, now averaging about three hours. These long tow times mean heterogeneous bottom habitats are sampled during the tow, so the diversity of species caught increases as the dominance of one or more "targets" declines, and in all likelihood survival of the animals in the catch also declines. Species once considered non-target or "bycatch" have become components targeted by generic trawl effort. Therefore, the concept of "retained bycatch" has given way to target "species mixtures" in recent years in this fishery.

Discard problems of the region's fisheries are manifested in several important ways: (1) marketable species too small or otherwise prohibited from landings are nevertheless retained in the gear and are subsequently discarded, (2) species for which no current market exists are caught simultaneously with

commercial or recreational species and are discarded, (3) various fleet sectors compete directly for landings or indirectly through bycatch interactions, and (4) non-fishery bycatch species, including marine mammals, turtles, and birds, are inadvertently killed. These issues are elaborated in the discussion which follows.

Discards of Small Fish

The discard of sublegal sized fish is significant in many fisheries, and stems primarily from the incompatibility of minimum size regulations with the regulated mesh sizes in use. Thus, for example, yellowtail flounder, with a minimum legal size of 13 inches, are caught with net meshes that retain a substantial portion of fish at and below this size (Figure 5). The example of the fate of the strong 1987 year class of Southern New England yellowtail flounder is illustrative of a number of features of the discard problem in the region. The magnitude of yellowtail flounder discards of the 1987 year class is given in Figure 6. From these discard estimates and landings-at-age data, it is determined about 77 million fish from the 1987 year class were landed through 1992, of which 46.5 million, or 60%, were discarded. Most discards occurred at ages 2 and 3, when the mesh sizes in use (4 - 5 1/2 inch diamond) retained large numbers of fish less than 13 inches in length. The foregone value of this catch due to discards is conservatively estimated to exceed $50 million.

The discard rates of sublegal sizes of species, such as yellowtail flounder and haddock, appear to vary directly with year class strength. Given low abundance of alternative ages in the stock or other valuable species, strong incoming year classes appear to attract effort, in spite of the necessity of discarding substantial fractions of the catch. Thus, one consequence of overexploited fishery systems is they encourage short-term high exploitation of incoming year classes to the ultimate detriment of long-term yields and stock biomass. In contrast, fishermen in some areas, such as the Gulf of Alaska, tend to avoid strong incoming year classes of species, such as sablefish, since the value per unit weight increases with size (R. Methot, NMFS/AFSC, personal communication). In the latter case, the presence of substantial quantities of other age groups in the exploited population offers an alternative to targeting recruits and is a direct consequence of more moderate exploitation rates.

A substantial quantity of the catch of some species is derived by recreational fishing on bluefish, summer flounder, scup, striped bass, and others. Discard rates of recreational fisheries of the region have increased in recent years owing to a combination of increased size limits, the institution of recreational bag restrictions, and a move to catch and release in recreational fisheries. Not all fish released by recreational fisheries survive, but this fraction is generally poorly understood. Understanding the potential impacts of recreational discards on mortality rates of the stocks will require a more detailed study of hook and release mortality rates.

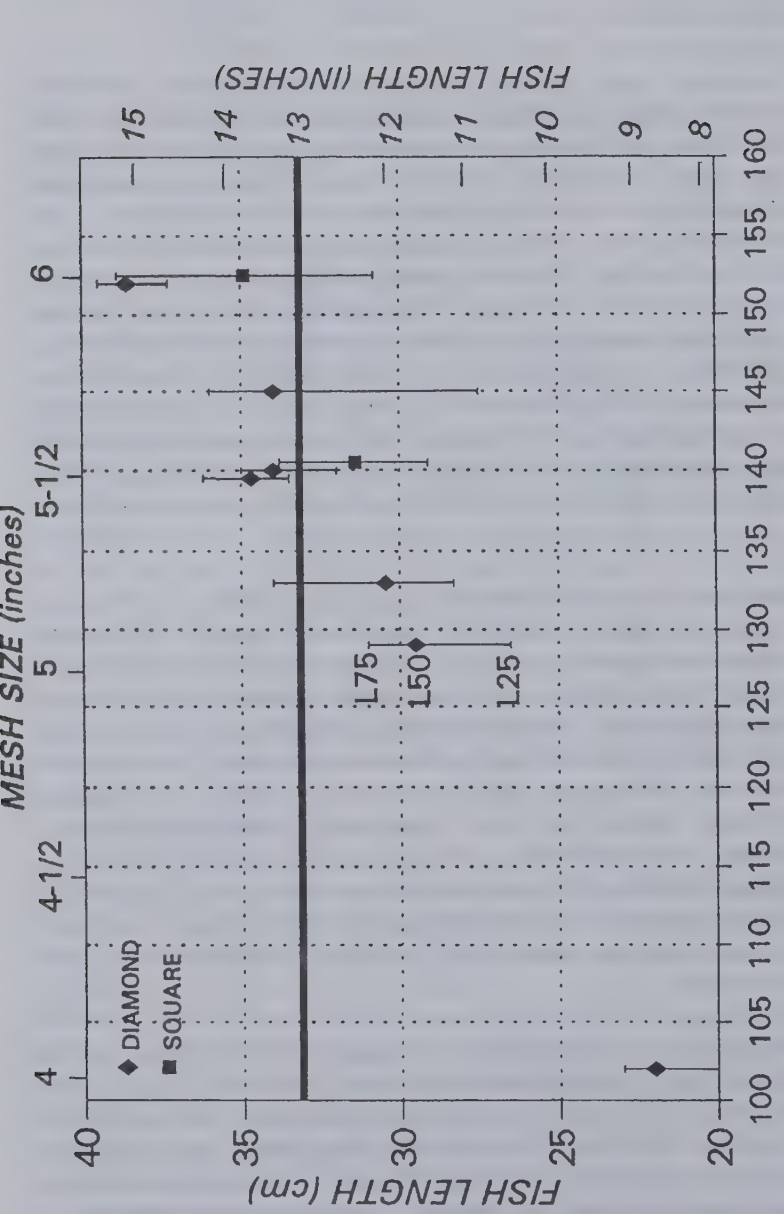


Figure 5. Estimated values of fish length at 50% selection (L-50), length at 25% selection (L-25), and length at 75% selection (L-75) for yellowtail flounder, based on nine research studies. Data for diamond and square mesh studies are plotted separately. Selection data are plotted against the experimental cod-end mesh size used in the various studies. Predominant mesh sizes in the fishery are 4 to 5 1/2 inches, diamond.

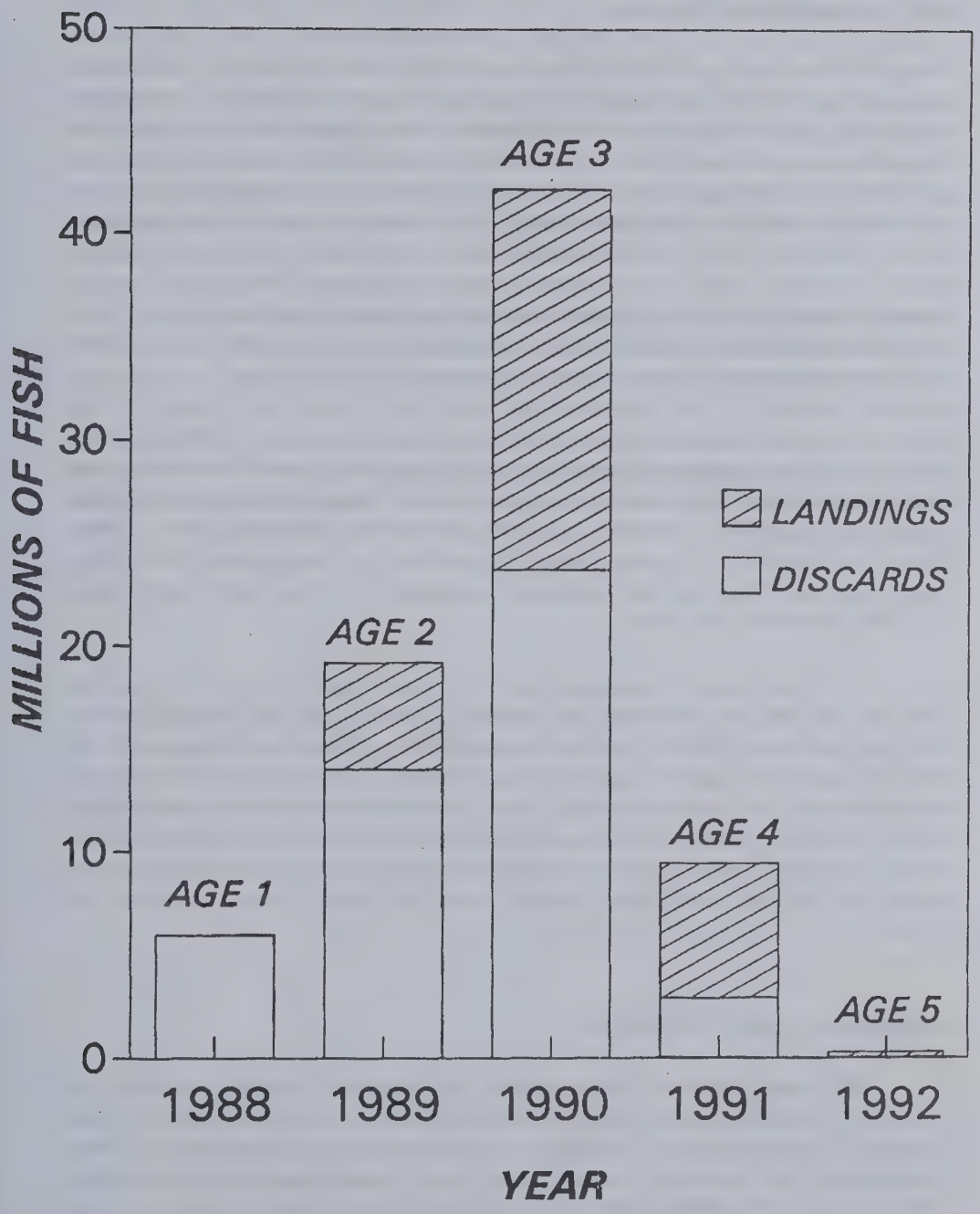


Figure 6. Estimated catch (landings and discards) of the 1987 year class of southern New England yellowtail flounder, 1988-1992. Data are presented for landings and discards separately. Total catch of the year class was 77 million fish (age 1-5), with 46.5 million (60%) discarded.

Catch of Non-Marketed Species

The catch of non-marketed species in many of the region's fisheries is relatively high. For example, the predominant species caught in the directed fishery for yellowtail flounder in the Southern New England region is little skate (*Raja erinacea*) (Murawski 1991). The species is not used for human consumption and only a limited quantity can be sold as bait. Thus, large quantities are discarded. Likewise, other trawl and gillnet fisheries of the region catch and discard large quantities of spiny dogfish (*Squalus acanthias*), red hake (*Urophycis chuss*), sculpins, sea raven (*Hemitripterus americanus*), four-spot flounder (*Lepidorhombus boscii*), ocean pout (*Macrozoarces americanus*), and others. Most of the discards from the Gulf of Maine sink gillnet fishery, targeted at cod, pollock and spiny dogfish, result from the catch of unmarketable species.

The catch of species not brought to market is doubly troublesome to fishermen. First, substantial quantities of fish catch are discarded, in many cases dead, for want of a market, representing some potential foregone economic opportunity. Moreover, the recent increases in abundance of some species, such as skates and dogfish, has exacerbated the problem of interference with fishing operations, since these fish are handled but generate no revenue and are becoming a larger fraction of the total catch.

The development of economic uses for these species may in some instances hold the key both for improving the efficiency of harvesting and ensuring species selective harvesting practices do not have unintended ecosystem consequences for the community of animals subject to harvesting. For those species currently underfished and uneconomic to bring ashore, more effort is needed to develop their market potential. Even if the revenues generated by such species simply cover the costs of handling, the advantages of such a strategy are bycatch species will be more fully utilized rather than "wasted" and the overall fishery economy will expand.

Competition Among Fleet Sectors

The trend towards more complete utilization of fishery resources has resulted in increased specialization of fisheries and harvesting techniques. Given the highly mixed nature of catches in most fisheries, an increasingly important consideration is the extent to which catch and discard patterns in one fishery influence stocks available to fisheries concentrating on the shared resources. Gulf of Maine groundfish fisheries offer an example of the magnitude of yields foregone to competitive fisheries for shared resources (Figures 7 and 8), particularly as a result of discarding. Small mesh fisheries catch and discard large quantities of small roundfish and flatfish. Gillnet and large-mesh trawl fisheries compete directly for some species. At current levels of fishing effort, the cumulative

equilibrium value of groundfish landings in the region is about $90 million. What would be the value of the resource if discard mortalities were eliminated? To estimate the value of groundfish landings foregone to bycatch, the mixed-species, multi-fishery model described in Murawski et al. (1991) was re-run with discards eliminated. The relative values of landings with and without discards are described in Figure 8. The overall value of landings approximately doubles, with the majority of new benefits accruing to the two large-mesh trawl fisheries. Although only modest increases in benefits occur for the small-mesh trawl and shrimp fisheries, reductions in the discards of groundfish subsequently available to other fisheries result in substantial gains in overall benefits.

As this and other examples confirm, a holistic view of regional fisheries may offer important perspectives on the true opportunities available from bycatch mitigation. Efforts to reduce discarding of valuable flatfishes and gadoids in the shrimp fishery have recently included the mandatory use of shrimp separator devices. Other management regulations, such as increasing minimum net mesh sizes in groundfish trawl and gillnet fisheries and reductions in effective effort levels, will likely have significant overall benefits and change the distribution of benefits among the component fisheries.

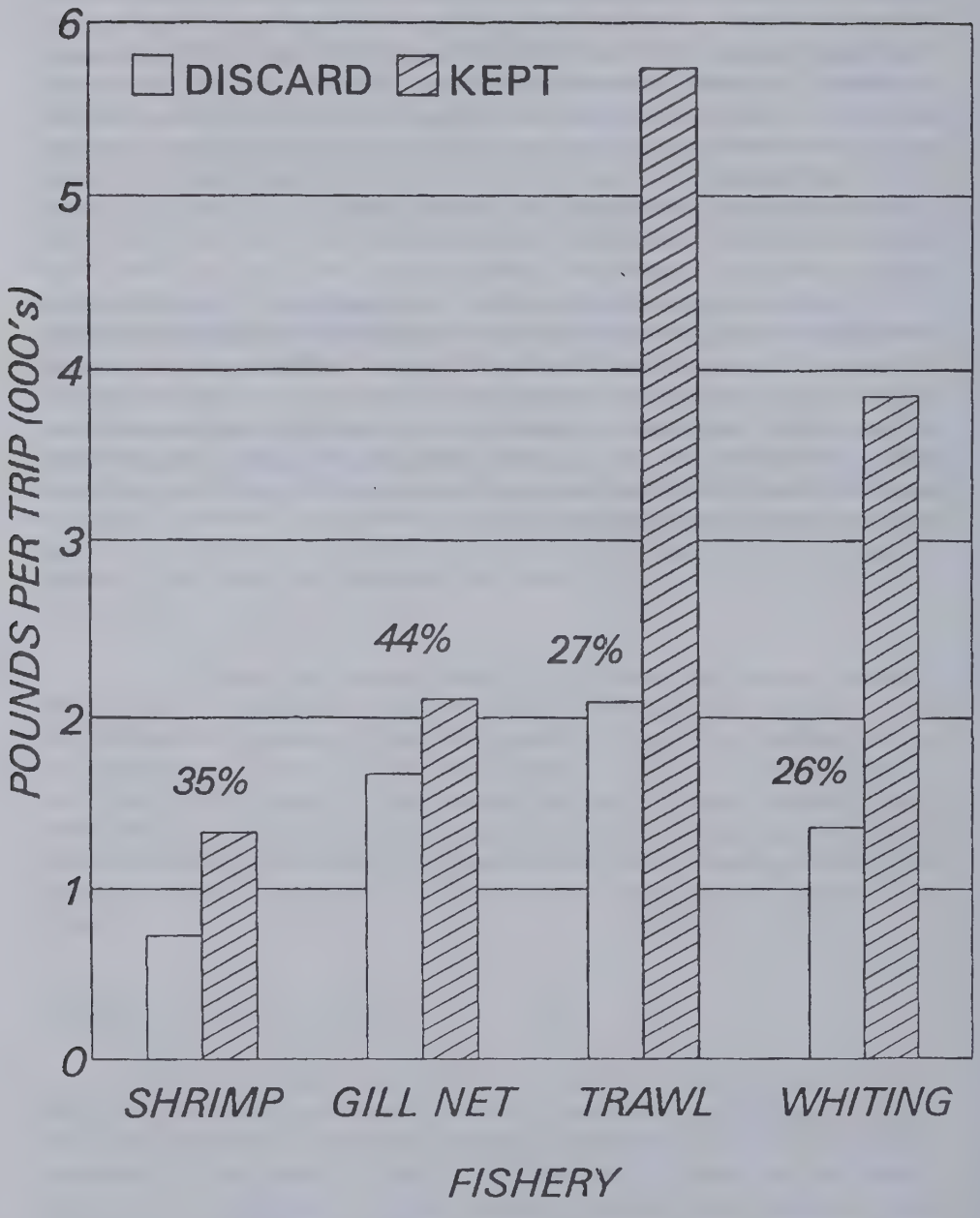


Figure 7. Results of sea sampling trip reports for four Gulf of Maine groundfish fisheries in 1991. Percentages of the total catch (in weight) discarded are given by fishery. Data are presented as pounds per sampled trip discarded and kept. Source: Murawski 1993.

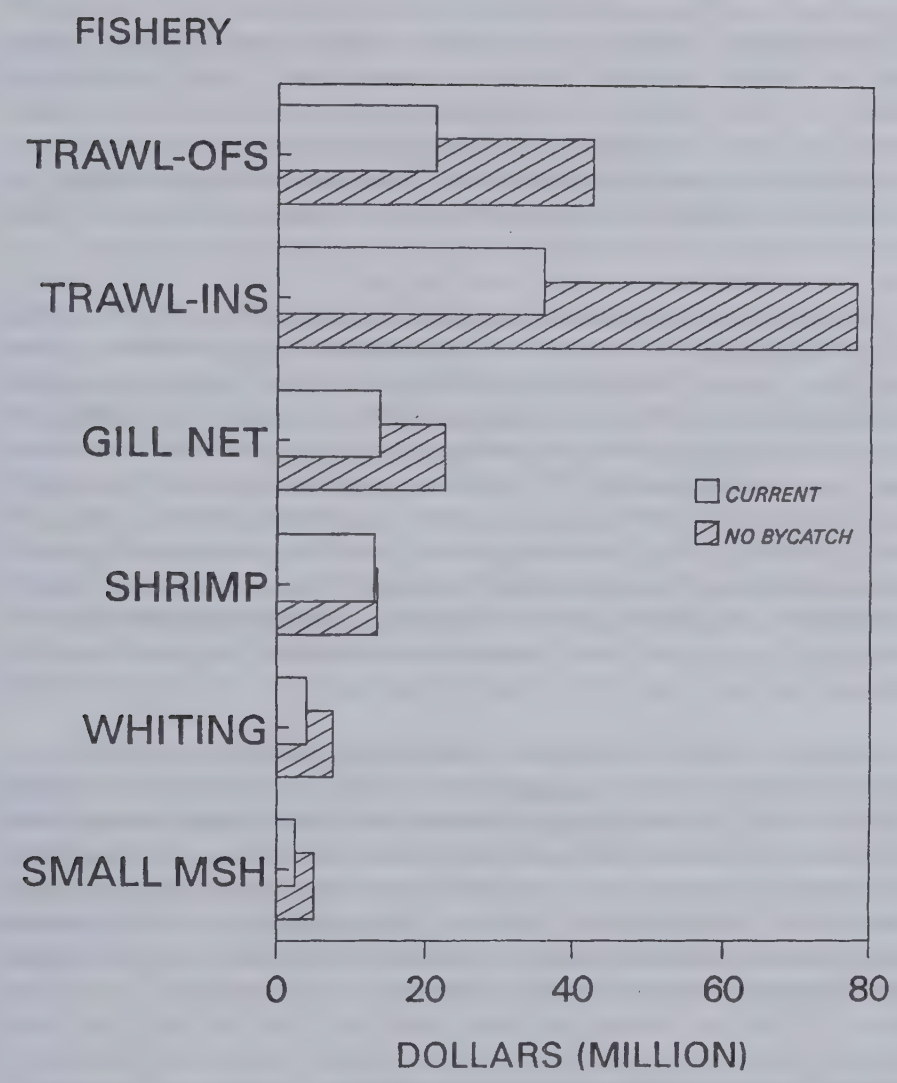


Figure 8. Calculated ex-vessel value of six fishery units exploiting Gulf of Maine groundfish resources under current bycatch conditions and assuming no discard mortalities for groundfish species. Analyses are based on an equilibrium mixed-species fishery model described in Murawski et al. 1991. Fisheries are: Trawl OFS = offshore trawl fishery using 5 1/2" mesh, Trawl INS = inshore trawl fishery using 5 1/2" mesh, sink gillnet fishery for groundfish, a trawl fishery directed at northern shrimp, a small-mesh fishery directed at silver hake (whiting), and a small-mesh fishery directed at other species. Total benefits approximately double, assuming mitigation of bycatch.

Catches of Protected Resources

The bycatch of protected marine mammal, turtle, and bird species in various fisheries has elicited increased scrutiny in recent years, both regionally and nationally. In general, mobile gear fisheries take few marine mammals and birds, and turtles are caught infrequently in trawl fisheries at certain times and places. Fixed-gear fisheries, however, do take these species, and the level of sampling of their bycatch and efforts to minimize the takes have increased significantly in recent years.

One of the most problematic bycatch issues concerning marine mammal bycatch is the kill of harbor porpoise in the groundfish sink gillnet fishery of the Gulf of Maine (Anon 1992a; NOAA/NMFS 1993). The fishery is pursued by about 250 small and medium-sized vessels, primarily targeting on cod, pollock, and spiny dogfish. Recent estimates indicate an annual bycatch of 900-2,400 harbor porpoise per year, representing 2%-5% of the extant population (NOAA/NMFS 1993). Managers have proposed a goal of reducing the rate of bycatch by half, and measures to do so are currently being contemplated. Some of these potential mitigation measures involve reductions in the overall amount of effective effort in the gillnet fishery, restrictions on effort in area/time blocks where the majority of porpoise bycatch occurs, and use of acoustic beacons to deter porpoises from being captured.

Catches of dolphins, pilot whales (*Globicephala melaena*), and other marine mammal species, as well as turtles, have been observed and monitored in offshore fixed gear fisheries, including pelagic gillnets and longlines targeting swordfish and tunas. These fisheries result in some "takes" (either kills or non-lethal encounters with these protected resources). Some of these fisheries have been restricted, in part due to their catches of these bycatches. Sea sampling of these fisheries to document mammal and turtle bycatches has been increased under auspices of both the Marine Mammal Protection Act and the Endangered Species Act.

Some Results from Comprehensive Discard Sampling

Comprehensive programs of at-sea sampling of catches and discards have been implemented for a number of U.S. fisheries in the Northwest Atlantic, including gillnets, pelagic driftnets, pelagic longlines, pelagic pair trawls, bottom trawls, fish and lobster pot fisheries, and dredge fisheries. The collection of adequate samples for routine discard estimation has been made for some fisheries beginning in 1989. The data derived from these sea sampling programs have allowed more complete assessments of the magnitude and causes of discards.

The bycatch and discard issues reviewed in the above section are important in many if not most of the region's fisheries. The development of methods to

mitigate problematic discarding has as its basis an understanding of the processes, both ecological and technological, resulting in these mixed catches of species and size groups. Some general analyses of discard and bycatch have been undertaken with sea sampling data collected over a wide range of the region's trawl fisheries (Murawski 1993).

Otter trawl fisheries of the region account for the majority of offshore catches and target a wide variety of demersal and pelagic species. A general linear model (GLM) was used to examine factors influencing overall discard rates and other attributes based on tow-by-tow sea sampling data collected from these fisheries during 1989-1992. Data in Figure 9 represent the relative magnitude of discard rates (all species weight discarded/all species weight caught) for a wide variety of trawl fisheries sampled. The classification of target species or species groups is determined by querying the captain as to the primary species sought during the trip. The target may be either an individual species or a species group. These target fisheries span a wide range of mesh sizes, areas fished, and other fishing techniques. Interestingly, relatively low overall discard rates occur in small-mesh fisheries directed to pelagic species, such as mackerel, butterfish (*Peprilus* spp.), squids, and tuna. The directed fishery for skates also results in low overall discard rates. Conversely, the highest relative discard rates result from fisheries directed for flatfish. As noted previously in this chapter, high overall rates of discard from flatfish fisheries result both from the catch of non-marketed species, such as skates and others, and the catch of sublegal sized target species.

The factors influencing the species diversity of sea sampled catches, including year, month, area, primary target species, cod-end mesh, tow duration, vessel tonnage, and depth, are evaluated in Figure 10. The F statistics corresponding to variables in the GLM are presented in this figure. Species diversity is defined as the inverse of Simpson's diversity index, ranging from 0 where a single species dominates the catch to 1 where all species are equally represented. The overall tow duration is by far the most important factor in determining the diversity of the catch. These analyses support the earlier observation that the ability to target individual species and thus to minimize unwanted bycatch may be severely compromised when tow times are increased, as in response to lower catch rates in the New England trawl fishery.

The effect of cod-end trawl mesh size on the overall discard rate is presented in Figure 11. These analyses are restricted to the Southern New England-George's Bank region for cod-end meshes of 4" and greater. These data represent a wide variety of target species, areas, and specific fishing techniques. Nevertheless, the decline in discard rate with increasing mesh size is clear for these fisheries. Discards here are defined regarding both non-marketed species and undersized target species. The adoption of larger mesh sizes, as proposed for the Northeast groundfish fishery, should produce lower overall rates of discard, all things being equal.

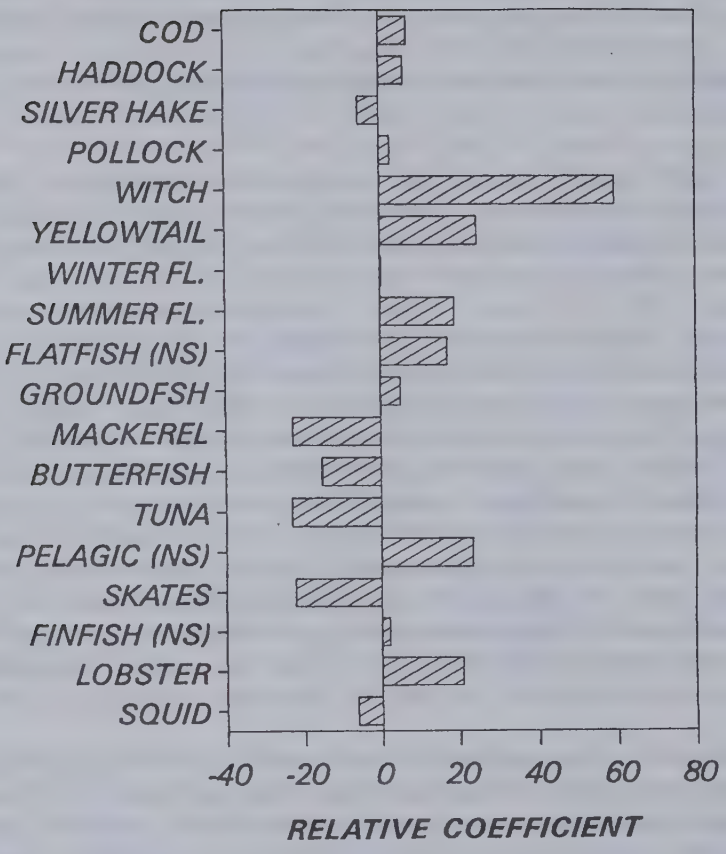


Figure 9. Relative effect of primary species sought on total discard rates from sea sampled otter trawl trips in the Northwest Atlantic off the U.S., 1989-1992. Data plotted are the standardized coefficients from general linear models incorporating primary species sought as a categorical variable. Thus, for example, highest overall discard rates occur for the witch and yellowtail flounder fisheries, whereas mackerel, tuna, and skate trawl fisheries have the lowest overall discard rates.

Analysis of sea sampling data from the diversity of the region's fisheries is critical to developing of effective strategies to reduce bycatch and discard interactions and determining the success of new management regulations implemented to achieve these goals. Collection of such data generally has strong support from the industry. Most sampling is now voluntary, although marine mammal and endangered species sampling can be mandated. Environmental groups also support these programs.

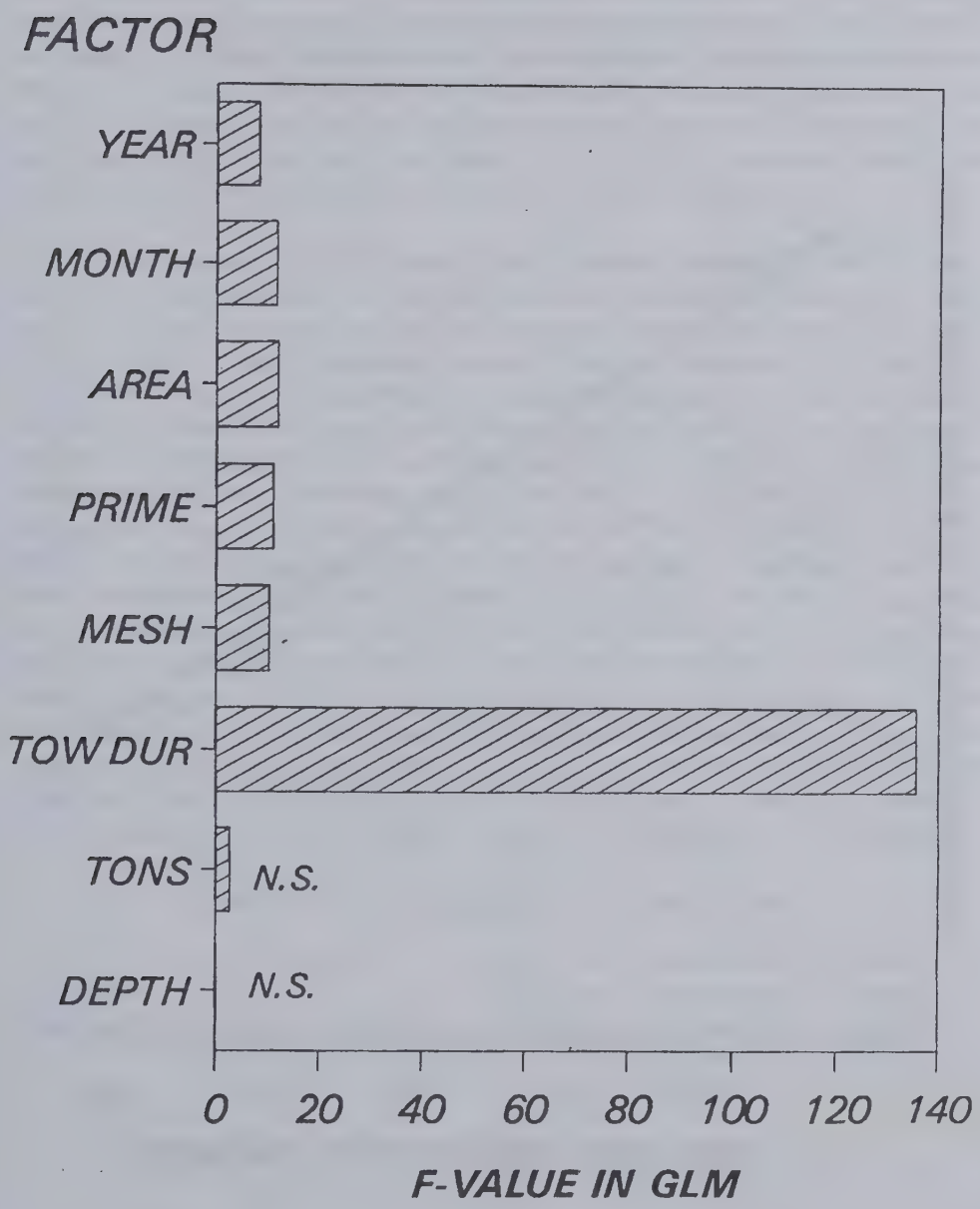


Figure 10. F-ratios from general linear models fitted to sea sampling data collected from otter trawl fisheries in the Northwest Atlantic off the U.S., 1989-1992. Dependent variable is species diversity (1/). N.S. = non-significant (P > 0.05) factor.

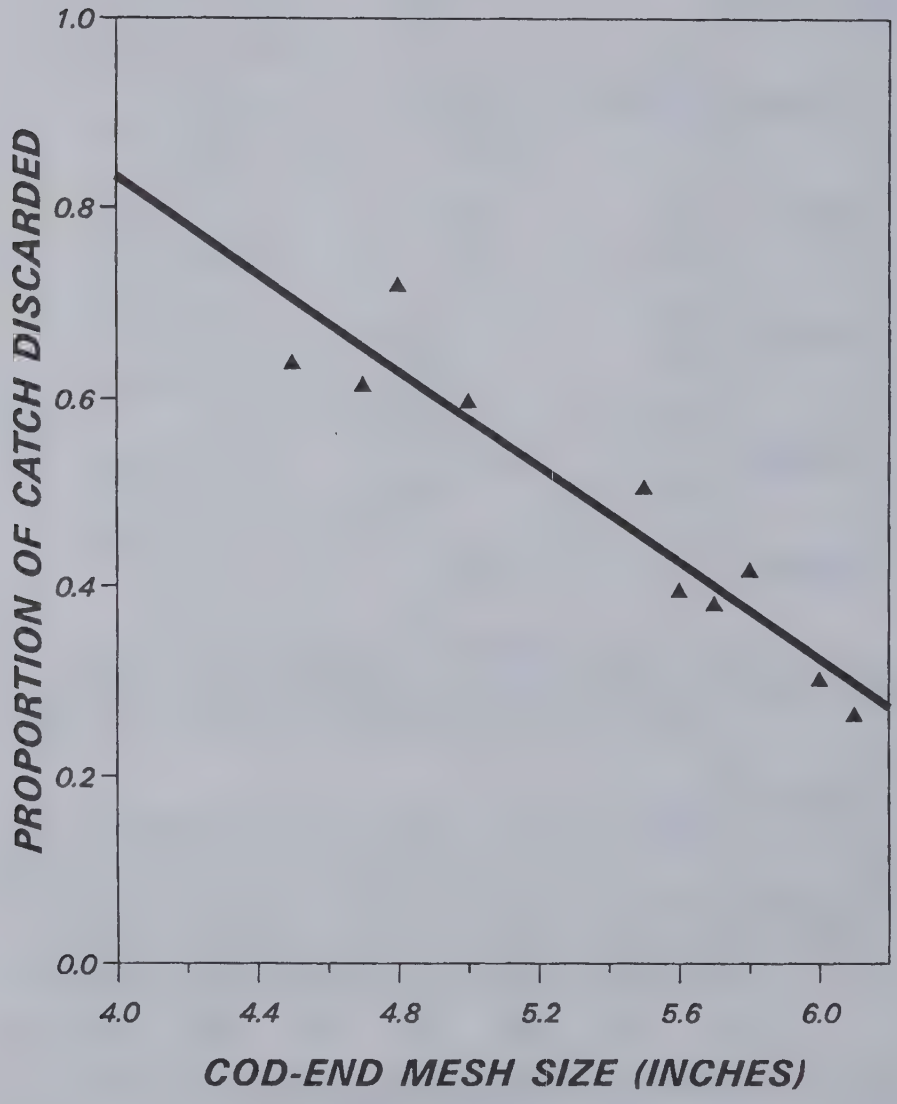


Figure 11. Effects of cod-end mesh size on the proportion of trawl catch discarded for all species caught in otter trawl sea sampling in the Northwest Atlantic off the U.S., 1989-1992. Data are combined for all primary species targeted and noted in Figure 9.

Incorporation of Discards into Assessments

The previous sections of this chapter have demonstrated high discard rates in some fisheries. A fundamental question is how these discards figure into the yield and stock potential of fisheries and the results of stock assessment calculations. Bycatch and discard data are expensive to collect, and sampling rates for discards may be substantially lower than for corresponding landings of a species, thus potentially mixing poor data with good. The case for including discards in assessments must justify the expense and effort of their collection.

The inclusion of fishery discard data in standard assessment models can in some cases drastically alter our perceptions of the status of exploitation of stocks and the balance of yields accruing from changes in regulations (Saila 1983; ICES 1986). Analytical stock assessments generally include a retrospective aspect and a prediction. Retrospective assessments often combine estimates of catch-at-age (or length) with relative indices of stock abundance from fisheries or research vessel sampling. Results of these retrospective calculations are trends in stock size and fishing mortality rates. Failure to account adequately for all components of the catch, landings and discards, may have important implications for the results (Table 30). If discards are primarily juvenile fish, then failure to account for them adequately will result in underestimates of fishing mortality, especially the stock size of the young fish. Implications for underestimating young fish discards may or may not have significant consequences for stock sizes and biomasses at older ages. Likewise, the overall goodness of fit may be improved, particularly if relative abundance indices include these young fish, but this effect may be variable. Inclusion of discards of adult fish will have a positive effect on estimates of stock biomass and to a lesser extent recruitment, stock numbers-at-age, and the overall goodness of model fit. The implications of additions of older discards for F calculations may be variable.

Table 30. Impact of discards on retrospective results.

AGE OF DISCARDS	F-AT-AGE	#s-AT-AGE	STOCK BIOMASS	RECRUITMENT ESTIMATE	GOODNESS OF FIT
YOUNG FISH	+	/	/	++	??
OLDER FISH	/	+	++	+	+

+ = POSITIVE EFFECT - = NEGATIVE EFFECT / = VARIABLE EFFECT

It is important to stress discards be treated consistently in all phases of the assessment process (ICES 1986). For example, the estimation of higher recruitment levels owing to the inclusion of young fish discards would be partially compensated by higher fishing mortality rates at these young ages. The net result would produce essentially the same overall yields in some types of calculations. The importance of discards to fishery predictions depends very much on the types of predictions being made, the assumptions of discard proportions over time (constant or variable), and the exploitation patterns at age (the partial recruitment) held constant or changed. Table 31 provides a general overview of the impact of discards on various predictions under several assumptions. This table is taken from the 1986 report of the ICES Working Group on Methods of Fish Stock Assessment (ICES 1986). In the simple case of a short-term TAC forecast, assuming constant partial recruitment and a constant fraction of discards in the catch, the inclusion of small fish discards has no effect on the predictions of yield. If, however, the discards are variable from year to year, but are predictable, then discards have a moderate impact on assessment calculations. Long-term calculations, such as equilibrium yield per recruit, particularly under conditions of variable discard proportions, are the most sensitive to the inclusion of discards in the assessment. When variable recruitment is combined with models assuming a changing partial recruitment (exploitation pattern), then the results are especially sensitive to the inclusion of discards, even when the discards are a constant proportion of the catch of some age groups.

Table 31. Impact of discards on fishery predictions. Source: ICES 1986.

PARTIAL RCT.	ASSESS. CALC.		CONSTANT PROPORTION	VARIABLE PROPORTION	
				PREDICTABLE	UNPREDICTABLE
CONSTANT (e.g., CATCH FORECAST, YPR, SSB/R)	SHORT-TERM FORECAST		0	**	0 + error
	LONG-TERM CATCH FORE-CAST	RELATIVE YIELD	*	***	* + error
		RELATIVE BIOMASS	*	**	* + error
CHANGING (e.g.,MESH ASSESS.)	SHORT-TERM LOSSES-GAINS		**	***	** + error
	LONG-TERM LOSSES /GAINS	RELATIVE YIELD	**	***	** + error
		RELATIVE BIOMASS	*	*	* + error

0 = NO; * = SMALL; ** = MEDIUM; *** = MAJOR

Some Examples

The use of discard estimates in routine stock assessments requires such data be available for the series of years included in the retrospective analysis. For most Northwest Atlantic fisheries, these discard estimates are available only since 1989. In some cases, direct estimates of discards via sea sampling have been supplemented with indirect methods like estimating the discarded proportions by applying commercial gear selection characteristics to population size compositions as determined from research vessel surveys. Discard estimates are routinely included in assessments of important Northwest Atlantic flatfish stocks, including yellowtail flounder, summer flounder, and American plaice (*Hippoglossoides platessoides*).

Figure 12 presents calculated fishing mortality rates for the 1987 year class of yellowtail flounder in southern New England. The fishing mortality on the cohort was extremely high for fully recruited ages (3+). For ages 1-3, discards accounted for a substantial fraction of fishing mortality. Effects of including or not including discards on assessment results have been examined for the stock. Failure to include discards overestimates the long-term yield and spawning potential of the stock for various assumed levels of fishing mortality and age patterns of fishing. Short-term yield forecasts are sensitive to the inclusion of discards when large year classes are present, such as the 1987 year class, but are insensitive when the stock is comprised of mostly older age groups. Similar results have been documented for other stocks. In some cases, such as silver hake, the inclusion of discard data has helped reconcile disparate trends in abundance, survival rates, and landings trends, compared to when only landings data were available.

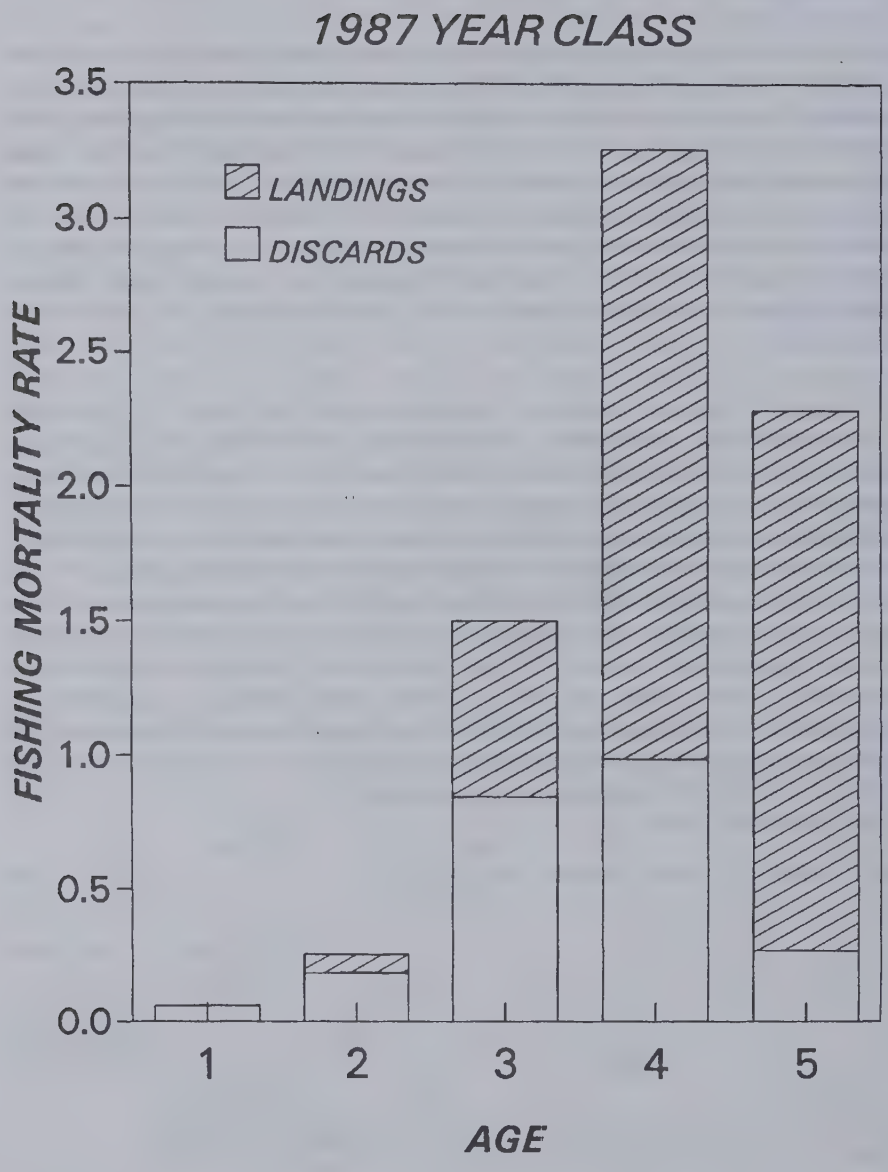


Figure 12. Calculated fishing mortality rates at age for the 1987 year class of southern New England yellowtail flounder. Source of mortality (discards vs. landings) is subdivided based in the relative proportions of the catch in numbers. Source: NOAA/NMFS 1993.

Summary and Prospects for Bycatch Mitigation

Bycatch, and in particular discarding, is pervasive and problematic in U.S. fisheries of the Northwest Atlantic. Discard problems are manifested in several important ways: (1) marketable species too small or otherwise prohibited from landings are nevertheless retained in the gear and are subsequently discarded, (2) species for which no current market exists are caught simultaneously with commercial or recreational species and are discarded, (3) various fleet sectors compete directly for landings or indirectly through bycatch interactions, and (4) non-fishery bycatch species including marine mammals, turtles, and birds, are inadvertently killed.

Bycatch is not a new problem faced in the region's fisheries, but the increased intensity and specialization of these fisheries and the heightened awareness of ecological implications of bycatches has placed added significance on finding approaches to their mitigation. Advantages to be achieved from successful bycatch mitigation programs include: (1) more efficient use of commercial species discarded because of size or quality, (2) establishment of markets for species not currently landed but taken as bycatch, (3) improved conservation of protected resources, and (4) increased access to resources shared by interacting fisheries.

Several regulatory approaches have been used or are being evaluated to reduce bycatch and discards. The use of a fixed grate in the northern shrimp trawl fishery has been mandatory since 1992. The intent of this technology is to allow legitimate fishing for shrimp with small mesh trawl gear, while reducing the discards of substantial quantities of undersized flatfish and roundfish. The success of this device in reducing discards is currently being evaluated through sea sampling. Another technological approach to reducing discards has been a move to larger mesh sizes in most of the region's trawl fisheries. Proposed Amendment 5 to the Northeast Multispecies (groundfish) FMP calls for 6-inch trawl mesh for most of the New England region. Furthermore, the intent of the plan is to specify minimum fish landing sizes at the 25% retention points for the 6-inch mesh, thereby resulting in virtually all of the catch being retained, it is hoped. Other gear improvements to minimize discarding are also being contemplated.

Area/time management measures have been proposed to minimize the catch of juvenile fish and to reduce harbor porpoise bycatch in gillnet fisheries. The development of a near real-time system to close areas wherein large concentrations of sublegal sized fish occur is intended to stop the practice of targeting local concentrations of incoming recruits. Such a system is heavily dependent upon current data and must be responsive enough to ensure timely closure of areas containing high concentrations of small fish.

Perhaps one of the most important measures that may mitigate high discard rates is the proposed reduction in the total magnitude of fishing effort. The

Northeast Fishery Management Council has called for a 50% reduction in days at sea over a five-to-seven-year period beginning in 1994. If the reductions in days at sea translate into reduced fishing mortality rates, then the reliance on incoming year classes should decrease and be followed by a greater degree of stability in year-to-year landings.

Various methods have been proposed to reduce harbor porpoise bycatch in the sink gillnet fishery. Obviously, an across-the-board reduction in gillnet effort would have some impact, but the catch of porpoises varies temporally and seasonally. Current work in this regard has been focused on defining area/time blocks accounting for the majority of porpoise takes. By limiting effort reductions to critical times and areas, it is hoped bycatch can be reduced while minimizing adverse economic consequences to the industry. Other fisheries, including pelagic gillnets, longlines, and pelagic pair trawls, are being closely monitored for bycatch of protected species. In some cases the fisheries have been severely limited or curtailed altogether when significant catches of these species have occurred.

The discard of unmarketable species, significant in some of the region's fisheries, will remain high pending either the development of new markets for these species or the use of harvesting gear minimizing their catch.

The inclusion of discards may be important in gaining an understanding of the overall yield potentials of the region's resources and the balances of gains and losses of yields among competing fleets when new regulations are being considered. Inclusion of discards in stock assessments is considered critical in many cases, and programs for discard data collection need to be expanded. Discard sampling data are routinely being used by managers to evaluate potential changes in the management program and to monitor the success of new regulations in reducing discarding.

The productivity, diversity, and sustainability of many of the region's fisheries are currently being seriously compromised due to overexploitation and high rates of discarding. If these fisheries are to operate on a sustainable basis with higher levels of production, reductions in the effective effort and a significant shift in the exploitation pattern to older animals will be necessary. The use of some or all of the above-described measures will be pivotal in attaining these goals. Continued monitoring of these fisheries through sea sampling is necessary to evaluate the success of various management measures in reducing bycatch and discarding.

CHAPTER 7 NORTHEAST ATLANTIC EXPERIENCES WITH BYCATCH, NON-TARGET MORTALITY, AND UNOBSERVED MORTALITY PROBLEMS

Introduction

The commercial fisheries of the Northeast Atlantic, like many commercial fisheries elsewhere, have their share of bycatch problems. In the past, these have been viewed as problems interfering with the proper management of the fisheries, rather than as threats to the conservation of endangered species or to the interests of rival groups like sports fishermen. However, perceptions of the problem are changing. Public awareness of perceived bycatch threats to other species is increasing. This is particularly the case for marine mammals and birds, but is likewise true for benthos and non-target fish species. Interfleet bycatch conflicts have also intensified.

This chapter seeks to provide a brief summary of the bycatch and analogous problems in Northeast Atlantic waters. It is intended to illustrate the problems rather than to form a comprehensive review of the field. This chapter covers the following four aspects:

1. The scale of the problems
2. The biological significance of the problems
3. Administrative responses to the problems
4. Underlying problems of stock assessment and management posed by bycatch

The examples are centered on North Sea fish stocks and European Community administrative responses because these are areas where the scientists of the region have most experience and where problems are particularly acute.

The best documented examples of commercial discarding in Europe are found in the trawl fisheries for roundfish (gadoids) in the North Sea. Here long-term at-sea sampling of discards of haddock and whiting have been carried out by the Scottish Fisheries Department. Scottish catches of these species are a sufficiently large percentage of the total international catch to allow reasonable extrapolation of these discard rates to unsampled catches. These calculations, documented in the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (Anon. 1993a), reveal high levels of discards in these fisheries. The discard rate has approached 50% of the total catch by weight of these species in some years (Table 32). The biological significance of this discard rate is discussed later, as are administrative initiatives to reduce it.

Table 32. Annual weights of haddock and whiting in human consumption landings, discards, and bycatches of the industrial fishery.

North Sea Haddock

Year	Total Catch (000t)	H.C. Landings (000t)	%	Discards (000t)	%	Industrial Bycatch (000t)	%
1980	216	99	46	95	44	22	10
1981	207	130	63	60	29	17	8
1982	226	166	73	41	18	19	8
1983	238	159	67	66	28	13	5
1984	213	128	60	75	35	10	5
1985	251	159	63	86	34	6	2
1986	220	166	75	52	24	3	1
1987	172	108	63	59	34	4	2
1988	171	105	61	62	36	4	2
1989	104	76	73	26	25	2	2
1990	87	51	59	33	38	3	3
1991	90	44	49	40	44	5	6

North Sea Whiting

Year	Total Catch (000t)	H.C. Landings (000t)	%	Discards (000t)	%	Industrial Bycatch (000t)	%
1980	212	91	43	76	36	46	22
1981	181	79	44	35	19	67	37
1982	129	71	55	26	20	33	26
1983	151	79	52	48	32	24	16
1984	135	77	57	39	29	19	14
1985	97	54	56	28	29	15	15
1986	154	58	38	78	51	18	12
1987	132	62	47	53	40	16	12
1988	127	51	40	28	22	49	39
1989	118	40	34	35	30	43	36
1990	147	42	29	54	37	51	35
1991	117	46	39	33	28	38	32

Non-target fishing mortalities are less well documented. Main areas of concern are the mortalities generated on marine mammals and birds from entanglement in gillnets and the destruction of sea floor species and habitat (killing of invertebrates) by ground trawl gears. This particular problem is associated with the heavily chained twin beam trawls used to catch flatfish, particularly Dover sole and European plaice (*Pleuronectes platessa*). There is also a concern with the impact of scallop dredges. These matters are often seen in the wider context of the environmental effects of fishing, encompassing not just bycatch problems, but also the perceived removal, particularly by industrial fishermen, of food species

important to birds, salmon, and other species. It also covers the fisheries-generated litter problem.

Besides the problem of discard mortalities, the problem of non-catch mortality rates (unobserved fishing mortality) has also been the focus of more discussion in recent years. Biologically the problem of mortality caused by contact with gear not resulting in catches is somewhat similar to the problem of non- or wrong-reporting of catches. These all result, if not estimated, in an incomplete inventory of fishing mortality leading to wrong assessments of the state of the fish stocks. Two main reporting problems exist in European fisheries. These are black fish (non-reported catch) and grey fish (catch which is misreported as to area or species), particularly prevalent in the North Sea flatfish fisheries for a number of years. For example, higher-valued sole was being misreported as plaice to enable the quota to be overrun. While not strictly bycatch problem, under-reported catch, like the bycatch problem, may be symptoms of fishing pressure being too great.

In brief, therefore, most of the North American perceptions of the bycatch problem are also recognized in Northeast Atlantic Fisheries, but there are local variations in the types of concern, like misreporting and environmental effects. Some of these may alter the ways in which society manages fisheries and affect the public image of fishermen. The traditional European public perception of fishermen as colorful or dignified "toilers of the sea" may have begun to shift, if only slowly and slightly, towards a view of some groups of fishermen as pillagers of the environment. If encouraged to develop too far, this perception could lead to the closure of fisheries.

The Scale of Bycatch Problems

At-sea observer programs are comparatively rare in European fisheries. As a consequence, many of the less obvious bycatch problems tend to be unquantified. While it is possible to give the scale of the problem for some fisheries, for most it is possible to give only some indication of the existence of a problem. Table 33 attempts to set out the seriousness of bycatch and other analogous problems for the various fisheries of the North Sea, particularly acute in some fisheries, but less in others. We will therefore discuss each problem in the context of the fleet or fleets where it is of greatest concern.

In practice, splitting the North Sea fisheries into just eight fleets is a gross oversimplification, since every country, every port, and every gear type and vessel size have different mixtures of species in their catches and different size compositions of catch that depend on when, where, and with what gear configuration they fish. Rocha et al. (1991), for example, classifies the English trawl fisheries into a continuous range of catch percentages. They show trawler behavior ranges from pure fishing for flatfish through mixed flatfish and cod fisheries, fishing for cod, and to fishing for haddock, whiting, and saithe. Thus, to

talk of the North Sea trawl fishery for gadoids is a considerable simplification, and the problems discussed may be more acute in some sectors of this "fleet" than they are in others.

Table 33. The severity of bycatch problems in a number of North Sea fisheries. (= possible problem, ** = problem, *** = serious problem, blank = no problem perceived). Source: Pope 1993.*

	Problem								
Fishery	Mixed Targets	Incidental Catches	Commercial Discards	Marine Mammal Kills	Bird Kills	Other Non Target Kills	Other Environment Impacts	Black Fish Landings	Grey Fish Landings
Trawl Fisheries for Gadoids	***	*	***			*		**	**
Trawl Fisheries For Flatfish	*	*	**			***		**	**
Industrial Trawl Fisheries for Sandeel, Pout		***				*	**		
Industrial Trawl Fisheries for Mixed Clupeoids	***	***					**		**
Purse Seine Fisheries for Pelagics			*	*					
Trawl Fisheries for Shellfish		**	***			*			
Gill Net Fishing				*	**				
Scallop Dredges			**			***			

Mixed Fishery Problems

The problem of a mixture of target species is a particularly serious one for the gadoid trawl fisheries of the North Sea. The main species sought are cod, haddock, and whiting. These are fish with intrinsically different growth rates, sizes and ages of maturity. Whiting reaching maturity at age 1 and about 23 cm requires a different fishing regime than cod that is 50% mature at age 4 at a length of 60-70 cm. Since both species are caught in the same gear, the mesh size adopted has to be a compromise between the two species. This compromise must lean heavily towards the need to catch the less valuable whiting (Figure 13). Cod is thus exploited at a much too young age.

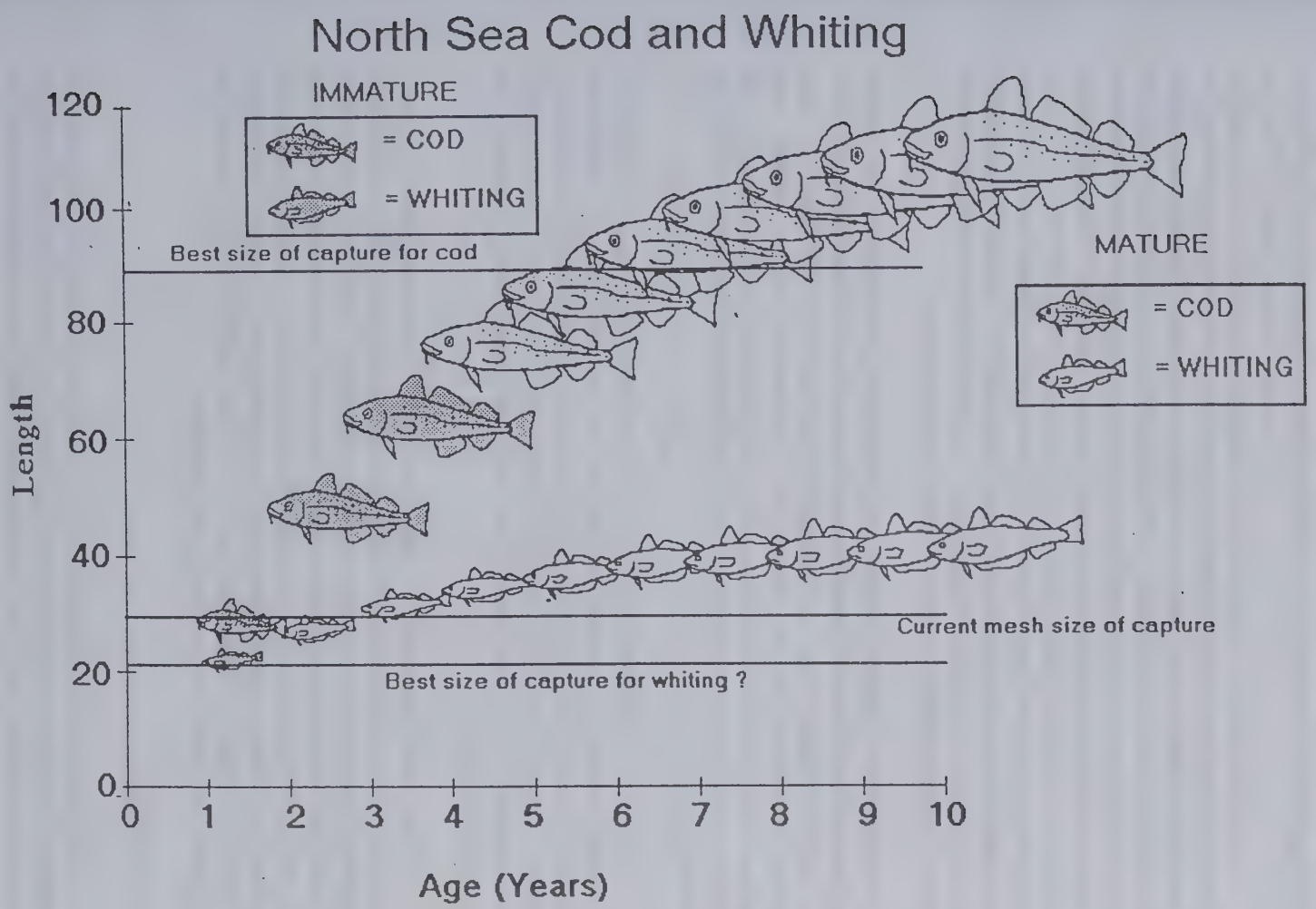


Figure 13. The relative size and maturity of cod and whiting at age.
Source: Pope 1993.

The alternative strategy of exploiting the cod at an older age is adopted by some groups of trawl fishermen and also gillnet and longline fishermen, but they tend to lose out to fishermen using the legal minimum mesh size of 100 mm in whiting and haddock-oriented fisheries that also catch some cod.

The mixed nature of these fisheries produces uncomfortable compromises for minimum landing sizes. These are set at 27 cm for whiting, 30 cm for haddock, and 35 cm for cod. In fact, whiting has the smallest girth to length ratio of the three species. Consequently, the tendency of fishermen to adjust the rig of their gear to catch as many minimum-sized whiting as possible inevitably leads to undersized catches of haddock and cod which must be discarded. While regrettable, this practice sometimes makes good commercial sense in the shortterm. It is, of course, nonsense in the longer term. The elimination of discards is a relatively popular aim because they are seen as a waste. Moreover, if a conservation measure could be devised that would eliminate discards without losses to the landed catch, this would produce long-term gains without short-term losses.

The desire to catch the smallest legal-size fish springs from the fact that the three species have high exploitation rates and hence the bulk of the fishable stock is close to the minimum size. A generally lower level of exploitation has been scientifically advocated for this fishery for a number of years. Among other benefits, this might help fishermen to get out of the vicious cycle of fishing for the smallest available fish and would reduce the consequent discarding of fish below the minimum size.

It is also worth considering if bycatch problems are themselves a symptom of overexploitation. Fishermen operating at low profit margins may be forced to make very short-term decisions they might avoid in more profitable circumstances. If the bank is threatening to foreclose on a vessel loan, the owner is likely to take a very short-term view of the world and not to be too concerned about threats to his longer-term livelihood.

Mixed fishery problems are also a feature of the industrial fishery for sprat. While this fishery is nominally for the small clupeoid sprat (*Sprattus sprattus*) it takes very large bycatches of herring (*Clupea harengus*). Since the herring caught are small, this has a potentially damaging effect on the directed human consumption fisheries for herring. Because these bycatches are for the most part deliberate, they are classified here as a mixed fishery problem. Alternatively, it might be viewed as a problem of incidental catch, but since the herring catch frequently exceeds the sprat catch, this would be a misleading classification.

Incidental Catch

The problem of incidental catch is more clearly seen in the North Sea industrial fisheries for demersal species, particularly in the case of the fishery for Norway pout a small (<20 cm) gadoid species found in the northern North Sea.

Its distribution overlaps that of small haddock and small whiting, and bycatch mortalities are generated on the youngest ages of these species. It is a particular cause of friction with commercial fishermen who also suspect the industrial fishery for sandeel of causing similar problems for cod in the central North Sea, though available evidence does not support this.

Table 34 shows the estimates of fishing mortality by age of haddock and whiting partitioned between the mortalities caused by commercial landings, by commercial discards, and by the industrial bycatch. The scale of the discard problems and industrial incidental catch problems in these fisheries is thus well described in mortality terms.

Incidental catches also occur in trawl fisheries for shrimp and prawns (*Nephrops*) which take incidental catches of small gadoids and flatfish. These effects are less well quantified.

Table 34. Fishing mortality by age for haddock and whiting generated by human consumption landings, discards, and bycatches of the industrial fishery for North Sea haddock and North Sea whiting. Source: Pope 1993.

North Sea Haddock (average 1987-1991)

Age	Total Catch F	H.C. Landings F	%	Discards F	%	Industrial Bycatch F	%
0	0.005	0	0	0.001	20	0.004	80
1	0.141	0.008	6	0.114	81	0.019	13
2	1.012	0.437	43	0.542	54	0.033	3
3	1.469	1.201	82	0.234	16	0.034	2
4	1.403	1.278	91	0.089	6	0.036	3
5	1.143	1.096	96	0.022	2	0.025	2
6	1.009	0.982	97	0.017	2	0.01	1
7	0.889	0.875	98	0	0	0.014	2
8	0.951	0.948	100	0	0	0.003	0
9	1.053	1.053	100	0	0	0	0
10	1.243	1.24	100	0.003	0	0	0
11	1.029	1.029	100	0	0	0	0

Table 34. (continued)

North Sea Whiting (average 1987-1991)

Age	Total Catch F	H.C. Landings F	%	Discards F	%	Industrial Bycatch F	%
0	0.026	0	0	0.003	12	0.023	88
1	0.178	0.003	2	0.062	35	0.113	63
2	0.506	0.079	16	0.21	42	0.217	43
3	0.902	0.412	46	0.284	31	0.206	23
4	1.219	0.85	70	0.228	19	0.141	12
5	1.562	1.201	77	0.254	16	0.107	7
6	1.536	1.332	87	0.05	3	0.154	10
7	1.416	1.235	87	0.067	5	0.114	8
8	2.141	1.957	91	0.047	2	0.137	6
9	1.584	1.57	99	0	0	0.014	1
10	1.584	1.57	99	0	0	0.014	1

Commercial Discards

As described in the previous section, commercial discards are a serious problem in the trawl fisheries for gadoids. They are also a problem in the flatfish trawl fisheries where undersized flatfish and over-quota cod are discarded. Discarding of undersized commercial species is also a feature of the trawl fisheries for shellfish. Generally these problems have not been investigated so comprehensively as in the gadoid fisheries. Recently, however, the EC has commissioned research on a number of these problems that is likely to become available soon.

Non-Target Mortalities

Non-target mortalities of marine mammals and birds are a potential problem in the gillnet fisheries of the North Sea. Since these are mostly directed to demersal fish, such as cod, the problem is probably less acute in the North Sea than in areas like the western English Channel, Celtic Sea and Bay of Biscay where gillnets are used for pelagic species such as bass and tuna. Seabirds and harbor and grey seals (*Halichoerus grypus*) have generally increased in the North Sea area, suggesting mortalities caused by fishing gears are generally insufficient to cause problems at a population level. The situation with small cetaceans is much less clear. Accurate time series do not exist, but evidence points to a decline. Cetaceans are impacted by some purse seine fisheries, as well as by gillnets. Anon. (1992) summarizes the current information on all environmental effects of fishing in the North Sea area.

Another concern with the direct effects of fishing on non-target species is that of heavy ground gears on benthic species. The heavy chain ground gears used by twin-beam trawlers can penetrate some sediments to a depth of 6 cm and cause significant non-catch mortalities and discard mortalities on benthic species in the trawls' path. The global effects of such mortalities are not clear. This is because, although these gears sweep in an area greater than the total area of the North Sea each year, much of this effort may be concentrated on selected tows and areas. Daan (1991) attempts to quantify these effects by area, and Anon. (1992) gives the areas impacted by different fishing gears in the North Sea.

The non-target fishing mortality rates generated by a fleet should, in general, be no higher than the fishing mortality rates it causes on the target species. A higher mortality rate on a non-target species would imply the two species have a very similar distribution and the catchability of the gear for the non-target species is higher than for the species it was designed to catch. This seems unlikely. However, while a non-target species may suffer lower fishing mortality rates than a target species, the adverse effects of the mortality may be greater if it is impacting a species with a vulnerable life history strategy, such as a lower fecundity and a higher size and age at maturity.

These effects of fishing can be seen to some extent in the changes generated in the overall size distribution. The size composition of fish in the North Sea shows a heavy erosion of the larger sizes. Some larger species of fish have certainly become uncommon in the North Sea (common skate, halibut). Comparisons of the North Sea fish size composition with that of George's Bank can be seen in Pope et al. (1988) and show the North Sea to be much more eroded system.

Other Environmental Effects of Fishing

Apart from direct bycatch effects, there are a number of potential environmental effects of fishing. One is the potential competition between fishermen and seabirds and other species which forage fish, such as sandeel. The lack of forage fish has produced breeding failures in bird populations on the Shetland Islands. However, it appears birds often exploit the resource at a younger age than the fishery. Hence, if fishing produces an effect, it must be through reducing the spawning stock size sufficiently to affect recruit numbers. As is the case with most fish species, the existence and form of the stock recruitment relationship for sandeel are difficult to establish, due to the large amount of variation in the recruitment series. Bailey (1991) and Bailey et al. (1991) discuss the relationship of the Shetland breeding failures to sandeel recruitment.

Fishery-Generated Food for Scavengers

Another environmental effect of fishing is the positive influence of discarded fish and fish offal on the population growth of scavenging seabirds in the North Sea area. Furness (1993) calculates the total number of scavenging seabirds has

increased from about 37,000 breeding pairs in 1900 to about 614,000 pairs today and attributes this increase to the availability of fish offal and discards. Positive effects resulting from discarding and non-catch mortality probably exist for benthic scavengers, but these have not been quantified.

The Biological Significance of Bycatch and Related Problems

Mixed fishery problems have been the focus of extensive biological studies in the North Sea area. The publications presented at the ICES Multispecies Symposium (Daan and Sissenwine 1991) give a good recent overview of this work. The problems can be divided into those of technical interactions and of biological interactions.

Studies of technical interactions are concerned with the fishing mortality simultaneously generated on a range of fish species and ages by the action of fishing fleets. They thus describe the practical constraints of feasible combinations of fishing mortality on different species and ages of fish. The biological interaction problem is concerned with understanding the interactions between fish species.

Technical interaction studies alone can be of value in describing the short-term effects of fisheries management. For example, the degree to which a series of fleet catch quotas are compatible with the patterns of mortality the fleets generate would be informative. Another example would be estimates of the likely short-term losses some measure, such as a mesh increase or a closed area, might cause particular fleets. The longer-term effects of management in a mixed fishery require an understanding both of the technical interactions and of the likely biological consequences of changing the exploitation on selected species and ages of fish. Such work is able to comment on the biological and economic effects of bycatches, discarded catches, and industrial bycatches.

The ICES Multispecies Working Group (ICES 1984, Pope 1991) and the Technical Measures Working Group of the Scientific and Technical Committee of the EC (STCFWG) have made considerable progress in understanding the main biological and technical interactions occurring in the North Sea. The Multispecies Working Group has collected stomach content data systematically from the chief North Sea fish predators and interpreted them through Multispecies Virtual Population Analysis (MSVPA). This is a technique using commercial fisheries catch-at-age data and fish stomach content data to estimate both the past fishing mortalities and the predation mortalities on main fish species in the North Sea. These form the basis of forward-looking simulations usable to determine the average long-term consequences of changing patterns of fishing.

The STCFWG has constructed commercial catch-at-age data by species, national fleets, quarter year, and ICES rectangles (1/2 degree of latitude by 1 degree of longitude). This enables the fishing mortality generated on a range of

species by each fleet in any subarea to be estimated. These results are of considerable worth in evaluating the results of technical conservation measures, such as seasonally closed areas or areas where gear restrictions are in force.

Plans are in hand to combine the methods and results of both working groups under the recently formed ICES Long-Term Management Measures Working Group (Anon. 1993b). Some major problems remain to be solved:

1. Stock recruitment relationships of the various species
2. Biological interactions between species occurring in their early life
3. Migrations of fish between areas
4. Practical economic problems concerned with the deployment of fishing effort

This last problem is particularly important. It arises because if fishermen are faced with a new regulation, they have a number of possible options, for example, a conservation box imposed on a fishing ground so that in certain seasons only large mesh nets could be used. Such measures can be seen in the North Sea in the cod "box" and the plaice "box" on the continental coast of Europe. When such measures are imposed, fishermen have the choice of fishing in the box with the new mesh size, fishing elsewhere in the North Sea with the conventional mesh size, fishing outside the North Sea altogether, or stopping fishing. In what proportion these options will be taken up is uncertain and may well change through time. Clearly the options chosen will influence the outcome of the measure.

Certainly it will never be possible to predict exactly the outcome of regulations, but the available analyses of the North Sea fisheries do help to describe consequences and act as thinking aids. A main conclusion from the work carried out so far is that many technical measures such as closed areas have unsuspected side effects and may not achieve their primary aims to the extent intended. An example of this is the cod "box," an area in the German Bight of the North Sea designed to protect young cod in their nursery areas by allowing fishing only with a larger than standard mesh size. Preliminary calculations of its effect by the STCFWG suggested relatively little conservation benefit for cod, although the fishing mortality was reduced on younger ages of whiting, a potential predator of young cod, and on sole. Similarly, calculations of the MSWG suggest the apparent long-term conservation benefits of mesh increases in the gadoid fishery might be undermined by increases in predation caused by releasing the relatively small whiting from fishing pressures. This is a result where the existence or non-existence of a stock recruitment relationship for cod could critically affect the results.

The example given above indicates the analyses of mixed fisheries can provide counter-intuitive results. This is particularly the case for technical conservation measures where the potential exists for making dramatic shifts in the balance of exploitation of different species. A further problem with technical conservation measures is they are frequently very uneven in their impacts on

different fleets. Closing an area may well cause short-term losses to fishermen who fished there previously while perhaps generating long-term gains for another group of fishermen. Problems of this sort make it difficult to maintain equality of sacrifice and so make agreement on such management measures difficult. The alternative of reducing the overall amount of fishing may be more equitable and have at least the potential to reduce fishing costs. It will not eliminate damaging bycatch problems, although it could reduce their impact.

To illustrate this latter approach, simulations of the main North Sea fisheries were made using a modification of the method of Shepherd (1988). This method uses results from multispecies virtual population analysis (MSVPA) to make steady state predictions for the various fleets and fish stocks. These take account of the known biological interactions between the species and the technical interactions between groups of fleets. The fleets shown in the following illustrative model are an aggregated description of a far more complex fishery. Table 35 shows the steady state catches that might be expected from current effort levels and the catches that the model predicts following a 50% cutback in effort of the trawl fleets. These fleets are:

1. The human consumption fishery for cod, whiting, saithe (*Pollachius pollachius*), and haddock (RNDFISH-HC). This fleet uses a variety of gears, but trawls are the most important. It generates discards shown separately (RNDFISH-DI).

2. The small-mesh industrial fishery for fish meal conducted with bottom trawls for Norway pout and sandeel (sandlance) (INDUST-DM). This fishery also takes bycatches of whiting and haddock.

3. The small mesh industrial fishery for fish meal conducted with pelagic trawls for sprat (INDUST-PEL). This fishery also takes bycatches of herring.

4. The flatfish fishery mostly conducted with beam trawls which fishes for plaice and sole (FLATFISH F).

5. The other two fisheries for human consumption herring (HERRING-HC) and for mackerel (MACKEREL) are conducted mostly with pelagic gears such as purse seines. Neither of these fisheries generates bycatch, so their effort was not reduced in the model runs.

Table 35. The comparison of landings by main fleets at current effort levels and at 50% of trawl and other demersal effort. Source: Pope 1993.

CATCH ('000 tonnes)
Current Effort

STOCK	COD	WHITING	SAITHE	MACKEREL	HADDOCK	HERRING	SPRAT	NOR.POUT	SANDEEL	PLAICE	SOLE	TOTAL
RNDFISH-HC	177	57	165	0	131	0	0	0	0	0	0	530
RNDFISH-DI	24	47	0	0	93	0	0	0	0	0	0	163
INDUST.-DM	0	71	7	0	9	0	0	309	591	0	0	987
INDUST-PEL	0	10	0	0	0	194	211	0	0	0	0	414
HERRING HC	0	0	0	0	0	146	0	0	0	0	0	146
MACKEREL	0	0	0	192	0	0	0	0	0	0	0	192
FLATFISH F	0	0	0	0	0	0	0	0	0	142	22	163
TOTAL	200	184	172	192	233	340	211	309	591	142	22	2596

CATCH ('000 tonnes)
Trawl and other Demersal Effort Halved

STOCK	COD	WHITING	SAITHE	MACKERE	HADDOCK	HERRING	SPRAT	NOR.POUT	SANDEEL	PLAICE	SOLE	TOTAL
RNDFISH-HC	164	48	198	0	56	0	0	0	0	0	0	466
RNDFISH-DI	11	26	0	0	28	0	0	0	0	0	0	65
INDUST.-DM	0	38	5	0	3	0	0	100	368	0	0	515
INDUST-PEL	0	5	0	0	0	102	136	0	0	0	0	243
HERRING HC	0	0	0	0	0	154	0	0	0	0	0	154
MACKEREL	0	0	0	192	0	0	0	0	0	0	0	192
FLATFISH F	0	0	0	0	0	0	0	0	0	152	23	175
TOTAL	175	117	203	192	88	257	136	100	368	152	23	1810

The model is based on a series of heroic assumptions and should be viewed as illustrative of the problem rather than as a definitive description or prediction. A major difficulty in making predictions is recruitment levels have varied systematically over the past two decades and the appropriate recruitment levels to use are therefore unclear. The model uses recruitment levels which, with current effort levels, would give the average catches of the past two decades for all species except mackerel. Mackerel has been at a depressed level throughout this period and recruitment levels were set to give a catch nearer a longer-term level. Values of fish at age are used based upon recent levels.

The results of the model shown in Table 36 indicate a 50% cutback in effort for the demersal fisheries and the pelagic industrial fishery would:

1. Make marginal reductions in the landings of the roundfish fleet, this resulting mostly from a reduced catch of haddock, but compensated by an increased catch of saithe.

2. Reduce the discards from the roundfish fishery.

3. Reduce the catch of both industrial fisheries, also sharply reducing the bycatches of whiting, haddock, and herring.

4. Marginally increase the catch of the human consumption herring fishery.

5. Leave the mackerel fishery unchanged.

6. Increase the yield of the flatfish fishery.

The change in the species mix reflects both the conservation benefits of the reduced effort and changes in predation levels for some species. Thus haddock and Norway pout suffer reductions in catch of more than 50%. It is a feature of biological interaction models that effort reductions do not generate as large an increase in yield as do single species models. This is because the larger stocks of predatory fish cause increases in natural mortality.

Estimates of the value of the various fisheries are shown in Table 36. These indicate effort reduction causes smaller losses in value than in catch for the roundfish fishery and correspondingly larger gains in value for the flatfish fishery, resulting from fish in both fisheries caught on average at larger and more valuable sizes. Despite the large reduction in effort, the total catch value is only marginally less than what would be obtained with current effort levels. However, the costs of four of the fleets have been halved. Table 37 attempts to show how profit levels might change with the effort change. The analysis assumes current profit levels to be 5% of the catch values of each fleet, although this is probably optimistic. With this assumption it is then possible to make a calculation of the profit that would be made if the four trawl fleets cut back their effort. Substantially increased profits are registered by the roundfish and the flatfish fisheries, but the profit remains either unchanged or only slightly higher for the industrial fleets due to increased predation on their target species and for the pelagic fleets which did not reduce their effort. The effect of halving the demersal effort would also presumably halve the mortality rates on the non-target species caught in these fisheries.

Table 36. The comparison of value of landings by main fleets at current effort levels and at 50% of trawl and other demersal effort.

VALUE (Millions of ECU's)
Current Effort

STOCK	COD	WHITING	SAITHE	MACKEREL	HADDOCK	HERRING	SPRAT	NOR. POUT	SANDEEL	PLAICE	SOLE	TOTAL
RNDFISH-HC	218	61	118	0	126	0	0	0	0	0	0	523
RNDFISH-DI	0	0	0	0	0	0	0	0	0	0	0	0
INDUST.-DM	0	5	0	0	1	0	0	22	41	0	0	69
INDUST-PEL	0	1	0	0	0	14	15	0	0	0	0	29
HERRING HC	0	0	0	0	0	46	0	0	0	0	0	46
MACKEREL	0	0	0	100	0	0	0	0	0	0	0	100
FLATFISH F	0	0	0	0	0	0	0	0	0	167	134	301
TOTAL	218	67	118	100	127	59	15	22	41	167	134	1069

VALUE (Millions of ECU's)
Trawl and other Demersal Effort Halved

STOCK	COD	WHITING	SAITHE	MACKEREL	HADDOCK	HERRING	SPRAT	NOR. POUT	SANDEEL	PLAICE	SOLE	TOTAL
RNDFISH-HC	222	53	147	0	59	0	0	0	0	0	0	481
RNDFISH-DI	0	0	0	0	0	0	0	0	0	0	0	0
INDUST.-DM	0	3	0	0	0	0	0	7	26	0	0	36
INDUST-PEL	0	0	0	0	0	7	10	0	0	0	0	17
HERRING HC	0	0	0	0	0	49	0	0	0	0	0	49
MACKEREL	0	0	0	100	0	0	0	0	0	0	0	100
FLATFISH F	0	0	0	0	0	0	0	0	0	214	150	364
TOTAL	222	56	147	100	59	56	10	7	26	214	150	1047

Table 37. Comparison of approximate profit (million ECU) at current effort and with 50% reduction of effort in all but the herring human consumption and mackerel fisheries.*

STOCK	Current Profit Est.	50% Trawl Effort Profit Est.
RNDFISH-HC	26	233
RNDFISH-DI	0	0
INDUST.-DM	3	3
INDUST-PEL	1	3
HERRING HC	2	5
MACKEREL	5	5
FLATFISH F	15	221
TOTAL	**53**	**470**

*Assumes (1) current profit is 5% of catch value, (2) prices are affected by changes in fish size but not by landings volume, and (3) effort costs are reduced in line with mortality rates.

Administrative Actions to Reduce Bycatch Problems

The Common Fisheries Policy (CFP) of the EC was reviewed recently after its first 10 years of operation. The official review document (Anon. 1991) is a good source of information on current perceptions of bycatch problems in the EC. Fisheries under the CFP of the EC are controlled by direct conservation measures, such as total allowable catches, and to a lesser extent by indirect limits on fishing effort. They are also controlled by technical conservation measures, such as mesh regulation, restrictions on the way gears are rigged, minimum size limits for landings, and closed areas and gear-restricted areas. A number of derogations from the main mesh size regulations are allowed, subject to restrictions on the use that can be made of the reduced mesh size. These restrictions are sometimes in the form of limitation on the minimum percentage of target species that may be caught. They may also specify a maximum limit on the percentage of the catch that can be formed of non-target species. Other derogations may be in the form of limitations on the area fished. These regulations can be seen in EC Fisheries Legislation No. 3094/86. Table 38 shows a summary of mesh derogations.

The technical conservation measures can be seen as most obviously directed towards controlling bycatch problems. Mesh size regulation is a measure to reduce bycatches and the discarding of young fish, since the choice of minimum mesh size affects the species mix caught.

Table 38. Minimum net sizes for EC Region 2 (excluding Skagerrak and Kattagat) as laid down in EC Conservation Regulation, No. 3094/86, as amended.

Area	Target Species	Mm	Minimum % of target species	Maximum % of protected species
North Sea (ICES IV and adjacent IIa south of 64°N)	All	100		100
	Sole	80	5	100(f)
West of Scotland (ICES VI) (North of 56°N)	All	100		100
West of Scotland (ICES VI) (South of 56°N)	All	80		100
All Areas	Whiting	90	50	10
	Norway lobster	70	30	60
All Areas	Mackerel Horse mackerel Herring Squid/Cuttlefish Pilchards Blue Whiting	40	50 (or 80 cumulative)	10
	Prawn (Pandalids) Shrimp (Crangon spp.) Deep Water Prawn (Pandalus borealis)	40	30	50
All Areas except south of 52°30'N	Norway Pout Sprat Blue Whiting	16	50	10
	Sandeels (1 Nov. through Feb.)	16	50	10
	(1 March through Oct.)	-	50	10

Restrictions on the way gears are rigged are in general designed to prevent the selective effect of the mesh size being undermined by codend attachments, such as top-side chafers. Recent legislation has discouraged the practice of ballooning codends to make them retain smaller fish. This is achieved by restrictions on the circumference of codends. Legislation has also allowed the insertion of square mesh panels with mesh sizes smaller than the minimum mesh size. These keep an area of open mesh in the vicinity of the codend and is thought to improve the selection of trawls for whiting and haddock. These panels are also used in the

derogation fisheries for *Nephrops* (scampi) to reduce bycatches of young haddock and whiting in this prawn fishery.

Minimum landing sizes (MLS) are imposed on important commercial species to provide a simply enforced backup to mesh regulations. A number of closed or gear-restricted areas have been chosen to reduce certain bycatch problems. Herring spawning areas have been closed to avoid overfishing spawning concentrations and disturbing egg carpets. Specific areas have been chosen to protect the young ages of cod and plaice, for example, the cod and plaice boxes on the continental margins of the central and southern North Sea. These are closed to all but local vessels and to vessels using large mesh size in their nets. Similarly, the Norway pout box was created to prevent small mesh industrial fishing in areas off the east coast of Scotland where young haddock and whiting are abundant.

Derogations from the main demersal mesh regulations allow bottom trawl fisheries for some of the smaller North Sea fish species. Small mesh nets are used for catching Norway pout and sandeel, but have maximum bycatch limits on human consumption species. Recently a derogation fishery for whiting was legalized with lower limits on the target species and maximum bycatch limits on named commercial species like cod and haddock. This was designed to allow whiting to be caught in a separate fishery. In principle, this might enable mesh sizes to be increased in fisheries for cod and haddock while enabling whiting to be caught under the derogation. Unlike most other derogations, this one is backed up by a one-net rule. The one-net rule requires the catch composition to correspond to that allowed with the largest meshed net carried. This is a regulation designed to close a legal loophole existing with derogation bycatch limits, the defense against excessive catches of the bycatch species resulting from sets made with a standard mesh net fished on the same trip. While the one-net rule is not yet an EC requirement for other derogations, the U.K. has unilaterally imposed it on other national fisheries carried out under derogations.

To discourage discarding, vessels are not allowed to carry grading machines when fishing for pelagic species using small-mesh nets, but some other management measures require certain fish to be discarded. Specifically, there is a requirement to discard fish under the legal minimum landing size (MLS) and over-quota fish. In practice, fishing under derogations may also encourage discarding of non-target fish beyond the allowable percentage. The argument for legal requirements to discard is they discourage breaches of the prime management measures. For example, MLS are set to discourage undersized nets being used. Traditionally they have been set at the L_{25} level of the mesh size (the fish size at which 25% of the fish are retained by the mesh). Thus, on average, an MLS requires a fisherman using the minimum mesh size to discard the part of his catch his gear retains which is smaller than the level. In practice, because fishing mortalities in the North Sea are high, many of the fish may be near or below the minimum size. For some fishermen it is economically beneficial in the shortterm to try to adapt their gear to retain as many fish as possible above the MLS. This means that instead of

corresponding to the L_{25} of the mesh, the MLS may correspond to a much higher percentage retention. This, of course, implies more discards, since the gear is retaining smaller fish.

Derogation bycatch limits may also require discarding in years when the non-target species are abundant and the target species scarce. However, it has been noted arguments for increases in the bycatch percentage of a derogation are often based upon official landing statistics, so it would seem probable derogation bycatches are at best lightly policed in some countries and they may not always lead to fish being discarded.

Norway, which is not an EC member, has a discarding ban requiring undersized or over-quota fish to be landed and sold on a nonprofit basis. These regulations are backed up by periodic closures of areas where small fish are abundant. Such legislation has been discussed within the EC but the consensus seems to be that in the very mixed fisheries of the EC, such a ban would simply force discarding to continue in a hidden fashion. This would hamper the correct estimation of discarding. Moreover, the possibilities of obtaining many successful prosecutions for breaches of a discarding ban would also seem slight. Without observers on every vessel, legal defenses for discarding would certainly exist. Fishermen could claim that discarding, observed by overflight, resulted either from the gear splitting or from the catch having to be slipped for safety reasons.

A number of selective gears have been developed by European gear designers. These use various partitions and mesh sizes to produce gears able to catch target species while reducing the bycatch of non-target species. The use of such gears is certainly desirable and there is no legal bar to their use, but without rigid enforcement they will be adopted only where the fishing industry finds their use advantageous. It would be difficult legally to specify current designs of such gear for mandatory use. Moreover, by their nature the selective features of such nets could easily be negated if fishermen were unconvinced of their value or were under financial pressure to reduce short-term catch losses. Voluntary uptake by the industry thus seems the best hope for the introduction of these gears at present.

There are few regulations specifically designed to avoid non-target mortalities on marine mammals and birds. Limits on the length of gillnets are in force to reduce the bycatch of cetaceans. Experiments have been carried out with sonic reflectors on gillnets, but so far such devices are not mandatory. Closed areas have been proposed for the scientific study of the effects of trawling on the benthos and also to provide refuge for benthic species. These have yet to be adopted, although some underwater marine reserves have been set up in inshore areas.

Underlying Problems of Stock Assessment and Management Posed by Bycatch Problems

In the section on the biological significance of mixed fishery problems, it was made clear that in order to evaluate the long-term effects of mixed fishery problems, very detailed biological and fisheries models are required. It also requires appropriate detailed datasets. This is particularly true where bycatch limiting measures, such as closed areas, need evaluation. These represent additional stock assessment tasks. They are possibly more necessary under a multinational fisheries system like the Common Fisheries Policy of EC than might be the case for a nationally managed fishery. A manager of a single-country fishery might be able to make pragmatic decisions about which regulations might help mitigate bycatch problems and to rely upon future monitoring to assess their value. In multinational fisheries, the various national administrators usually wish to understand the gains and losses to their own fleets before legislation is approved. This knowledge has obvious negotiating benefits, but equally obviously requires more sophisticated stock assessments.

Generally, the bycatch problem presents stock assessment scientists with additional difficulties. Chief of these is the need to estimate the levels of discarded fish and non-catch hidden mortalities, often difficult to do in an unbiased fashion. Moreover, since these estimates will be based upon at-sea sampling, the resulting numbers are likely to be more variable than other parts of the catch record. Including these results likely reduces the precision of the whole assessment, but leaving them out risks bias. This bias is likely to be particularly serious in the case of assessments of the effect of mesh changes.

The ICES Working Group on Methods of Fish Stock Assessment (Anon. 1986) considered the effects of under-reporting on estimates of population size and mortality made by cohort analysis and some biological reference points. They concluded from a series of simulations that constant under-reporting of catch at all ages had little effect on assessments except future catches were underestimated in line with the under-reporting rate. They also found suddenly increasing under-reporting rates led to underestimates of the current mortality rate. Under-reporting of older fish catches led to overestimated mortality rates.

In general, estimates of biological reference points were robust to these missing data. However, the change in mortality rate needed to reach the reference point was distorted in some cases because while target mortalities remained unchanged, the estimates of current mortality were altered.

No study was made of the under-reporting of young fish that would result from unestimated discards or non-catch mortalities. However, it should be expected that constant levels of such under-reporting would lead to underestimation of mortality rates on the ages affected. More abrupt increases might lead to underestimation of the mortality rate in the current year and underestimation of

recent recruitment levels. Variable levels of discarding might also undermine confidence in recruitment estimates.

Chapter Summary

Mixed fisheries with high exploitation rates, high bycatch rates, and high levels of discarding are the norm in the North Sea and in a number of other areas of the Northeast Atlantic. Bycatch, more particularly discarding, is perceived as a waste of potential commercial landings. Its elimination is sometimes seen as the one conservation measure that might not involve short-term losses to fishermen, but would require the development of more selective gears than are currently available.

In the Northeast Atlantic, bycatches of non-target species, such as seabirds, seals, and small cetaceans, occur and are a cause of increased concern to the public. Detailed models of the North Sea fisheries, including the technical and biological interactions, have been developed in ICES and EC study groups. These suggest bycatch moderating measures, such as closed areas and mesh changes, may have unexpected side effects. They may benefit fish other than the species intended and may also create predation-driven changes to the system.

The controls imposed by the Common Fisheries Policy of the EC have a number of technical conservation measures designed to reduce undesirable bycatches in the fisheries. These measures include minimum mesh sizes, gear restrictions, minimum landing sizes, derogations for catching small fish, and closed and restricted areas. Some of these measures impose a legal requirement to discard fish in some circumstances.

Proper assessment of fisheries with bycatch problems requires a greater intensity of scientific investigation, particularly in the case of multinational fisheries. Discarded catches and non-catch mortalities need evaluating if the assessments are not to risk some bias.

Where bycatch discards are a problem, technical measures are often seen as the solution. These might be of two types: (1) voluntary measures adopted by fishermen when a reduction in their bycatch rate is in their own interest, for example to reduce bycatches of small fish in shrimp fisheries that are a nuisance to discard, or to avoid the capture of sensitive species such as marine mammals. This approach is most likely to be successful when the reduction in bycatch represents no economic loss to the fishermen or may even represent a reduction in costs or work. (2) Compulsory measures are more likely to be needed when the reduction in bycatch implies an economic loss to some fishermen in the shortterm. The measures that can be adopted in this case are limited to those that can be legally defined and are reasonably enforceable.

An alternative to technical approaches to resolving bycatch problems may be using direct conservation measure like reductions in capacity, effort, or catch to

reduce the level of fishing mortality on target and incidental catches alike. This may be sufficient in some cases to reduce the impact of the bycatch to acceptable levels. In other cases it may increase the profitability of the fishery and serve to reduce the rate at which fishermen discount future benefits and losses, possibly increasing the time horizon of fishermen, who may then find technical measures more acceptable. Thus, this approach may increase the acceptability of measures intended to enhance long-term benefits to fishermen and the marine environment.

PART IV

POLICY, SOLUTIONS AND CONCLUSIONS

CHAPTER 8 EVOLUTION OF NATIONAL AND INTERNATIONAL POLICY CONCERNED WITH INCIDENTAL HARVEST DISCARDS

Research directed at understanding the consequences of fish mortality associated with the capture and discard of undersized target species and the imposition of regulations to reduce the catch of undersized species dates well back into this century. However, development of explicit national and international policies to deal with fish discards is of more recent vintage.

This does not imply attention to discards was not a subject of concern of earlier marine scientists and managers, but the focus of discard studies was much narrower. The post-World War II years was an era of rapidly expanding fisheries in which scientists and managers searched for strategies to avoid diminishing catches and optimize the use of whatever nature provided in terms of recruitment to exploitable resources. It was a period when yield per recruit analysis provided a management approach independent of information as to why fish stocks fluctuated. At the heart of this management concept was the establishment of mesh regulations designed to minimize the capture of unwanted small fish and optimize the capture of fish at sizes leading to the greatest possible yield, taking into account the amount of fishing effort and the biological characteristics of the species harvested (growth and natural mortality).

Discard studies for more than a quarter of a century following World War II largely involved developing an understanding of how to optimize sustainable catches of species through adjustments in codend mesh-size regulations for trawlers. Researchers were not oblivious to the catches and discards of substantial quantities of unmarketable species, but for the most part they felt either such catches did not constitute a threat to the populations of discarded species or tended to feel it was a non-issue.

In fact, even in the latter half of the 1980s, Bricklemyer et al. (1989/1990), referring to fisheries managers, noted that "In the first instance, where discard is a concern, it is usually characterized as a narrow problem, such as waste of a potential food source, interference with fishing operations, or excessive kills of high-valued commercial (for example, prohibited species) or protected species." With few exceptions, this observation aptly conveys the attitude still held by a significant sector of fishermen and fisheries managers.

Nevertheless, the nature of waste or potential waste resulting from non-selective fishing practices was clearly identified by many early researchers. In this respect it is interesting to see that Saila (1983), in discussing the nature of the discard problem only a decade ago, noted waste was often seen as a single problem and pointed out that "wastage in throwing back fish into the sea was seen as no worse than the underutilization of some stocks (squids, mesopelagic fish, etc.) or the overfishing of others." He also noted the problem of losses of future catches, such as mortalities to undersized discarded target species. Saila saw the growing need to deal more deliberately with the discard/waste problem largely in light of the growing world need for animal protein, stating "...the utilization of products now being discarded at-sea must be substantially increased."

Policy Development in the U.S.

The breadth of the emerging literature underscores the fact that the bycatch and discard issues have surfaced in recent years as high-priority fisheries management issues in developed and developing countries. Perhaps nowhere in the world has the incidental catch/discard issue received as much public policy attention as in the U.S. Conflicts emerged between the U.S. conservation community and the (1) U.S. ETP tuna industry, (2) high seas foreign driftnet fisheries, and (3) the Gulf of Mexico shrimp fishery. These marine mammal/fisheries conflicts, coupled with inter-gear discard disputes in the large-scale Alaskan groundfisheries and elsewhere and commercial recreational allocation disagreements, formed the substrate upon which a significant body of U.S. and international law was designed to address discard problems (Burke et al. 1993).

Freeberg (1992), provides an excellent chronology of actions taken in the fisheries of the Northeast Pacific leading to a growing diversity of regulations directed toward limiting levels of discards. The regulations include establishment of chinook salmon bycatch caps, target discard rates for foreign fisheries taking incidental catches of species of interest to U.S. fishermen, industry bycatch regulations, vessel incentive programs to reduce discards, "hot spot" closures, and allocations of pollock to midwater gear to reduce the incidental catch of prohibited species, given the "cleaner" characteristics of pelagic trawls.

Bricklemyer et al. (1989/1990), in his review "Discarded Catch in U.S./Commercial Fisheries," covers a series of specific discard issues in the U.S. and outlines a number of laws that specifically deal with or can be used to address discard problems. These include the U.S. Endangered Species, the Marine Mammal Protection, the Migratory Bird Treaty, and the Magnuson Fisheries Conservation and Management acts. Iudicello and Leape (in press) expand on this list, and Greenberg (1992) discusses the legal aspects of bycatchand discard issues.

By the early 1990s, the growing controversy over discards in U.S. fisheries had become a topic of debate among members of the American Fisheries Society

who published a policy on bycatch in the society's *Bulletin of Fisheries* (Perra 1992):

1. To encourage state and federal agencies to promote development, use, and implementation of bycatch reduction devices to conserve fish and wildlife.

2. To support the continuation and expansion of conservation engineering programs to reduce bycatch of undersize or non-target species.

3. To request states and other entities conducting research on turtle- and fish-excluder devices to develop and support programs to extensively field test all bycatch reduction devices and designs that allow for juvenile finfish escapement.

4. To encourage programs through its membership and publications and by other means that demonstrate the usefulness of bycatch reduction devices to the commercial fishing industry.

5. To support efforts to hold national and international conferences on conservation engineering in order to improve technology transfer between researchers and other groups developing bycatch reduction and other fish separator devices.

On a national level, the U.S. MFCMA, as reauthorized by Congress in 1990, notes that it is the policy of the Congress in this Act to "...ensure that national fisheries conservation programs consider the effect of fishing on immature fish." The Act directed the U.S. Secretary of Commerce to secure a ban on high seas gillnetting. About the same time, fear of the implications of regulations involving the catch and discard of sensitive species, such as turtles and certain finfish in the U.S. Gulf of Mexico and South Atlantic shrimp fisheries lead the U.S. Congress to adopt the Incidental Harvest Research Amendment Act. This Act prohibits the Secretary of Commerce from implementing regulations to reduce incidental harvests in the Gulf and South Atlantic shrimp fisheries until January 1, 1994.[30] Klima (1992) highlights the importance of this problem, noting the discard rate in high seas driftnet fisheries ranges between 50 and 300 individuals per metric ton of target species, while the discard rate for the Gulf of Mexico shrimp fisheries is close to 200,000 individuals per metric ton of target species taken.

The U.S. Endangered Species Act prohibits "taking" of any endangered species by any person subject to U.S. jurisdiction. The term "take" includes kill, trap, harass, pursue, hunt, shoot, wound, capture, collect, or attempt to engage in any such conduct. Even if a U.S. fishing activity were to capture an endangered

[30] The Act allows for a research period to find potential solutions to bycatch problems.

animal accidentally, it could be considered a "taking" (Bean 1983). The Act has already been used in several instances to modify fishing practices (Bricklemyer et al. 1989/1990).

Perhaps the most well-known marine mammal bycatch problem in the world is that involving the ETP tuna purse seine fishery. In the early 1970s, this fishery, dominated by U.S. vessels, set large purse seines around dolphins to capture schools of associated tuna. During this period, annual dolphin deaths were said to have reached a level exceeding 300,000 animals and involved several species (Marine Mammal Commission 1991). In order to address the dolphin catch and discard problem in the face of widespread attention to the issue in the U.S. and global press, the U.S. Congress incorporated into the MMPA a dolphin permit requirement for the U.S. tuna seine fleet.

In 1974, the National Marine Fisheries Service, responsible for administering the U.S. MMPA for pelagic species,[31] issued a permit regulation authorizing U.S. seine vessels to take an unlimited number of dolphins until December 1975. However, after this date the number of kills and concern over the impacts of these kills led to a series of increasingly constraining permitted kill levels. Regulations set an aggregate U.S. kill level for dolphins at 78,000 in 1976 and 1977, 51,945 in 1978, 41,610 in 1979, 31,150 in 1980, 20,500 in 1984. Total international fleet kills in 1991 and 1992 were 27,292 and 15,539 respectively (the current mortality level is $<4,000$ annually). Although the kill rate of dolphins dropped markedly, so did the number of boats in the U.S. tuna seine fleet. Between 1980 and 1984, the U.S. fleet numbers fell severely, from about 94 to 42 (Young et al. 1993), and in 1993 only a few U.S. vessels continue to operate in the ETP. However, a large international fleet continues to set on dolphin schools in the region (Hall 1994, pers. comm.).

The increased U.S. attention to discard research and management is noted by Murawski (1991) to be due, in part, to trends of increasing fishery effort and greater specialization of fisheries in recent years. In addition, there has been a growing importance placed on the effects of discard mortality on threatened or protected species. Murray et al. (1992) note a recent switch in interest from potential use of bycatch to "impacts on fish populations" and suggest this change of emphasis may in part reflect increased political sophistication of user groups.

Fox (1992) identifies four different facets of the discard problem: (1) allocation, (2) conservation, (3) legal or regulatory problems, and (4) those relating to the public ethic issue. The last issue, he notes, is the "most overlooked as a driving force of the bycatch problem and was an underlying factor in the emergence of the Marine Mammal Protection Act in the U.S. and modifications made in the U.S. MFCMA which address incidental catch and discard issues."

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[31] Includes coastal species such as the harbor porpoise.

Fox's first three problem categories are similar to those noted by numerous authors, but ethical concerns raise a new emerging issue. The point is well made that the U.S. public's ethical consideration of incidental catches and mortalities imposed on discarded non-target species, in particular marine mammals, turtles, and birds, served as a catalyst formulating early "bycatch" (discard) policy in the U.S. Congress. Ethical considerations may go well beyond the question of the continued viability (conservation) of the stocks in question. The capture of large quantities of these animals, regardless of the status of knowledge regarding populations of concern, was enough to ignite a political force which ultimately required major changes in the U.S. tuna seine fisheries and helped to formulate a U.S. policy providing for and leading to termination of high seas gillnetting in the Pacific.

The socio-economic implications of the public's perception of the ETP seine fishery for tuna and its associated porpoise take is reflected in the now famous Heinz Co. announcement that it would no longer purchase tuna caught in association with dolphins.[32] As noted by F. Alverson (1991), "There is no doubt that H. J. Heinz gave careful thought and agonized for a considerable time prior to the decision to make this announcement that was fostered by the U.S. public's ethical concerns and emotional attachment to marine mammals."[33]

Miles (1992a) concludes:

> In the U.S. the legal prohibitions concerning discards derive:
>
> ...either from the conflicting interest of gear types and therefore different groups of fishermen, or the desire to protect a variety of marine mammals and seabirds (non-consumptive uses).
>
> Conceived in this fashion, one realizes that the bycatch issue presents a powerfully multivalent political problem which involves at least three components:
>
> 1. Biological issues of great technical complexity facing tight constraints because of an inadequate knowledge base.
>
> 2. Contentious issues of who gets what and how much among different groups of fishermen. In this conflict, bycatch issues are used as surrogates for different allocation rather than conservation decisions.
>
> 3. Issues of emotion, values, and ethics concerning marine mammals and the political potency of the environmentalist coalition.

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[32] The "dolphin-safe" definition requires no purchase of driftnet-caught fish or fish caught in the ETP fishery if dolphins were encircled at any time during the ETP trip.

[33] Whether all seafood companies are subscribing to this policy and are in reality declining purchase of such tuna seems highly questionable (F. Alverson 1991).

There can be little doubt that the public ethic issues noted by Fox (1992) and emotional issues involving marine mammals (Miles 1992a) helped serve as a stimulus to forge international policies concerned with high seas driftnetting. The consequence of societal concerns with marine mammals is well reflected in U.S. policy dealing with high seas driftnet fisheries.

High Seas Salmon Driftnet Fisheries

Japanese driftnet fisheries for salmon have been carried out in the waters off Japan and in the Northeast Pacific since early in the century. But the explosive growth of the high seas motherships and land-based driftnet fisheries beginning in the early 1950s marked the beginning of the large offshore driftnet fisheries:

> ...The mothership driftnet fishery, which started with three motherships and 57 catcher vessels, quickly ballooned to 16 motherships and 506 catcher vessels in 1956. During its early development, the fishery operated throughout much of the North Pacific between 160°E and 175°W longitude and from 46°N to 62°N latitude. In peak years, as many as nine million tans[34] (about 450,000 km, or 270,000 miles) of driftnets were deployed in a season. To complete this picture, one should add six million tans deployed by the Japanese land-based fleet between 38°N and 45°N latitude and about 143°E to 175°W longitude. Japanese catches of salmon from the high seas driftnet fishery soared from about 3,800 mt in 1952 to over 100,000 mt in 1955. Similarly, the land-based catches rose from 23,600 mt in 1952 to over 72,060 mt in 1959. Catches of both fleets decreased throughout the 1960s and 1970s, and the Japanese mothership fleet activities were terminated in 1988 in the U.S. EEZ and part of the Bering Sea (Alverson 1992b).

The growth of these fisheries at the onset, particularly the mothership operation which fished off the coast of Alaska, were seen as highly detrimental to U.S. interests, but not as part of the bycatch and discard problem. Although conservation problems were highlighted in attempts to stop or alter driftnetting for salmon, the underlying economic consequence of interception of fish bound for U.S. and Canadian waters (allocation) was of equal or greater concern (Miles 1989).

The growing need to establish an institutional structure to deal with the expanding Japanese fisheries in the Northeast Pacific (Miles 1989) led to the establishment in 1953 of the International North Pacific Fisheries Commission (INPFC) between the U.S., Canada, and Japan. The Commission passed the now

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[34] One tan of salmon net equals 50 m (Fredin 1985).

famous "abstention principle"[35] which governed fishing activities in the Northeast Pacific region for most of four decades (Jackson and Royce 1986).

At first, U.S./Canada concerns within the INPFC regarding adjacent high seas salmon fisheries rested on (1) management problems resulting from mixed stock fisheries, (2) capture of immature fish diminishing their MSY (maximum sustainable yield), and (3) economic dislocation of U.S. and Canadian fishermen who were already using available surpluses from North American rivers. The breadth of the U.S./Canada concern was subsequently expanded to include the wastage of salmon resulting from "dropouts."[36] In aggregate, these arguments resulted in some adjustments in the distribution of salmon driftnetting giving temporary reprieve to the Japanese from the continued pressures mounted by U.S. and Canadian salmon interests (Jackson and Royce 1986).

In the INPFC debates in later years, the U.S., Canada, and Japan never agreed on whether "salmon of North American origin" qualified for abstention. Nevertheless, through economic and political pressures and tradeoffs involving Japanese interests in groundfisheries off Alaska and Canada, the U.S. and Canada managed gradually to displace the high seas mothership salmon fleet from the Bering Sea.

The ultimate political force proving most devastating to the continuation of high seas driftnet salmon fishery resulted from the coalescence of the interests of numerous U.S. sport and commercial fishermen and Alaskan Native American and conservation groups (Miles 1989). The former argued interception by Japanese fishermen of sockeye and chinook salmon bound for western Alaskan rivers was detrimental to the economic/social welfare of their members and complicated the conservation of the resources. The latter raised the problem of "bycatch," in particular the catch and discard of large quantities of Dall's porpoises, other marine mammals, and birds.

After passage of the U.S. MMPA in 1972, Japanese vessels operating in U.S. waters were required to have permits for the incidental capture of marine mammals, and following renegotiation of the INPFC in 1978, U.S. marine mammal observers were placed aboard motherships. The observer program verified that rather large numbers of Dall's porpoises were being taken in the high seas salmon gillnet fishery. Jones (1990), for example, estimated in excess of 10,000 Dall's porpoises may have been taken in 1982. The Japanese, encouraged by the U.S., did undertake efforts to reduce catch and discards of marine mammals and such experiments were begun. Nevertheless, the combination of legal actions,

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[35] A principle accepted by Japan requiring their fishermen to abstain from fishing stocks of fish in the Northeast Pacific region which were fished at the MSY level under scientific study and management.

[36] Dropouts are fish captured in nets that may die and subsequently drop out of the net, resulting in an unobserved mortality.

the inability to establish an OSP level,[37] arguments raised by conservation and North American Native groups, and probably the costs of high seas fishing (Miles 1989) ultimately led to the phasing out of the Japanese salmon driftnet fleets.

Squid Driftnet Fisheries

Driftnetting for squid in the North Pacific was initiated by Japan in the fall of 1978. This fishery quickly came into conflict with the historical near-shore Japanese jig fleet, and the driftnet fleet was subsequently restricted to the waters north of 20° and east of 170°E (Court 1981). The fleet expanded rapidly, and Japanese fishermen were joined by neighboring Korean and Taiwanese fishermen. By the early 1980s, the aggregate fleets from these three nations had soared to over 750 vessels, with squid catches in excess of 300,000 mt (Alverson 1992b).

The onset of the high seas squid fleets' activities immediately raised the ire of American fishermen who perceived salmon of U.S./Canadian origin were once again being intercepted and that catches were of enormous proportions. As noted by Johnson (1990), "Some estimates suggest this new and expanding high seas fishery caused a loss of 40 million salmon from Canadian and U.S. rivers in the last year, as well as the destruction of 50,000 marine mammals and a million seabirds...." As the fisheries grew, U.S. and Canadian fisheries bodies initiated studies to attempt to clarify the extent of marine mammal, bird, and salmon interception. The commitment to documenting the nature of the squid driftnet fishery was inspired by (1) growing observations and concerns of the U.S. albacore (*Thunnus alalunga*) fishermen, (2) evidence of illicit sales of salmon on the international market, and (3) early observer data supporting conservationists' claims that the fishery was impacting marine mammal and bird populations (Miles 1989). These observations provided a basis for promoting an expanded U.S./Japanese observer program in the fishery.

As a result of the growing disenchantment of U.S. fishermen operating off Alaska and Native and conservation groups, the U.S. government passed the Driftnet Monitoring Act in 1987. This law required the U.S. to negotiate observer monitoring agreements with any foreign government authorizing its nationals to conduct driftnet resulting in the taking of U.S. marine resources in waters of the North Pacific seaward of the EEZ (Northridge 1991a). Shortly after passage of the Act, a broad-based multinational observer program was initiated.

Meanwhile, the South Pacific island states had for some time been mounting a coalition opposing long, large-mesh driftnets, and in November 1989, together with Australia and New Zealand, opened for signature a Convention for Prohibition of Fishing with Long Driftnets in the South Pacific (FAO 1992). Interestingly, a report (Allan et al. 1991) of the South Pacific Commission completed as the result

[37] Optimal sustainable population.

of observations aboard Japanese driftnet vessels fishing for albacore and skipjack shows an overall discard rate (percentage of total species retained) during fishing operations in the Tasman Sea of 12%, of which three-fourths was discard of damaged target fish, small tunas, and dropouts. In the offshore fishery carried out in the sub-tropical convergence region, the overall discard rate was reported at 8% by number of target individuals retained, of which again three-fourths was damaged or small target species and dropouts. In the two observational sets, bycatch of non-target species constituted 3% and 2% of retained catch by number--a relatively low discard rate, considering the rates observed in many other major world fisheries (Freeberg 1992). Nevertheless, some marine mammals, birds, and turtles were taken, and the South Pacific community highlighted concerns over impacts of the high seas fisheries on local fisheries of the region.

The perceived threat of high seas driftnets rapidly became a national and international issue. Even before the results of the North Pacific observer effort could be completely analyzed (Burke et al. 1993), the U.S. Congress, responding to environmental advocacy group pressure and the growing leverage of the U.S. public, moved to establish a moratorium on the high seas driftnet fisheries and shortly thereafter to join with the U.N. in calling for the termination of such fisheries. Miles (1992a), for example, notes "the U.S. in 1989 led the charge in the U.N. General Assembly to stop high seas driftnetting based on the 'wastefulness' of this gear type."

There was little or no opposition in the U.S. Congress to the establishment of the moratorium or to the ultimate outlawing of high seas driftnetting. The fate of the high seas driftnet fishery was linked to:

1. Excessive capture of salmon of U.S. origin.

2. "Walls of death" which stretched across much of the North Pacific Ocean.

3. The capture of hundreds of thousands of marine mammals.

4. "Dirty" and wasteful fishing practices resulting in high rates of bycatch and discards.

5. Grave concerns about the impacts of driftnetting on the integrity and productivity of the pelagic ecosystem.

As the U.S. mounted its efforts to outlaw the high seas driftnet fishery, an attempt was made to uncouple its own coastal gillnet fisheries and those within the EEZs of other countries from the negative image cast on the high seas fishery. However, Northridge (1991a) in his extensive review of driftnet fisheries concluded that there are:

> ....few important differences between driftnet fisheries which are operated inside EEZs compared with those operated outside EEZs, except that effective management and regulation of those in international waters may be more difficult. The environmental impact of numerous vessels operating a few net sections in coastal waters may be equivalent to, or even greater than, a smaller number of high seas vessels which operate a greater number of net sections.

More recent studies (Freeberg 1992; Burke et al. 1993) have shown the action of the U.S. Congress preceded careful analysis of the data acquired from the different high seas driftnet observer programs (Japanese, Korean, Taiwanese) designed to verify bycatch and discard rates. Freeberg (1992) and Burke et al. (1993)--confirmed in our study--showed that incidental catch rates and discards of non-target species for the Korean and Taiwanese squid fisheries were significantly lower than those documented for the Japanese driftnet fishery and for most large-scale world fisheries undertaken within the EEZs of coastal nations. Although the level of sampling and the aggregate nature of the data reports make in-depth analysis of the available data difficult, significant areal differences in bycatch rates have been observed (Table 39). The results of the observer studies also indicated the incidental capture of salmon and marine mammals, birds, and turtles in the Korean and Taiwanese fisheries was low in relation to those observed in Japanese fisheries. Had bycatch rates for the Korean and Taiwanese fisheries been used to estimate impacts, different technical and scientific views regarding the impacts of high seas driftnetting may have emerged.

Regardless, even had the issue been considered in light of more recent information, it seems doubtful the outcome in the U.S. Congress would have been different. Although the salmon, marine mammal, and bird interception rates in the Korean and Taiwanese squid fisheries were relatively low compared to many fisheries, there was ample evidence the squid fishery constituted a staging area for illegal salmon operations to the north (Miles 1989; Burke et al. 1993). Further, the incidental albacore catch was impacting a stock apparently already overfished (Fox 1992),[38] and some marine mammal populations may have been threatened, over time, by the Japanese squid fishery (Mangel 1993). These concerns, plus the lack of transparency in the high seas driftnet squid fisheries and the presumed need for timely action provided the basis for congressional actions. But perhaps of greater importance, the issue was emotionally charged and vigorously pursued by the world press, who were being fed information by government sources, advocacy groups, and, at times, scientists unfamiliar with the problem. Finally, the numbers of marine mammals, seabirds, and other sealife killed in the driftnet fisheries were perceived to be ethically unacceptable to the U.S. public.

Thus, advocates of terminating all high seas driftnet fisheries successfully promoted a general ethical and philosophical view regarding driftnet fisheries, their

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[38] Albeit no international effort had previously been made to control albacore catches in other fisheries.

take of marine mammals, birds, and turtles, and the potential environmental degradation they induced. This helped to motivate a fast reaction by the U.S. Congress--a response which the international community, prodded by the U.S., was quick to endorse.

Table 39. CPUE rates (# per unit of gear) for various species groups in Japanese, Korean, and Taiwanese driftnet fisheries in 1990. Source: Freeberg 1992.

		Salmon	Sharks	Tuna	Billfish	Pomfret	Othfish	Seabirds	Mammals	Turtles
Japan	June	0.0005	0.0484	0.0002	0.0001	0.7002	0.0975	0.0045	0.0005	0.0000
	July	0.0094	0.0381	0.0002	0.0002	1.7577	0.2962	0.0096	0.0009	0.0000
	August	0.0033	0.0287	0.0224	0.0002	1.829	0.15	0.0243	0.0016	0.0000
	September	0.0001	0.0247	0.528	0.0007	1.829	0.1277	0.0185	0.0016	0.0000
	October	0.0000	0.0383	0.5417	0.0003	1.9201	0.0164	0.0059	0.0008	0.0000
	November	0.0000	0.0635	0.1213	0.0007	0.6285	0.0071	0.0148	0.0004	0.0000
		Salmon	Sharks	Tuna	Billfish	Pomfret	Othfish	Seabirds	Mammals	Turtles
Korea	June	0.0000	0.014	0.0027	0.0000	0.1301	0.0556	0.0011	0.0005	0.0000
	July	0.0000	0.0173	0.026	0.0003	0.7089	0.0131	0.0021	0.0002	0.0000
	August	0.0000	0.0387	0.2067	0.0005	0.0166	0.1385	0.0009	0.0001	0.0000
	September	0.0000	0.1041	0.1132	0.0001	0.0297	0.184	0.0024	0.0003	0.0000
	October	0.0000	0.0226	0.0744	0.0001	0.0356	0.0135	0.0051	0.0006	0.0000
	November	0.0043	0.0031	0.0095	0.0000	0.0214	0.0199	0.0052	0.0000	0.0000
		Salmon	Sharks	Tuna	Billfish	Pomfret	Othfish	Seabirds	Mammals	Turtles
Taiwan	July	0.0001	0.0137	0.0481	0.0001	2.1812	0.029	0.0043	0.0000	0.0001
	August	0.0000	0.0067	0.6351	0.0019	0.0874	0.0263	0.0005	0.0001	<0.0001
	September	0.0000	0.1562	0.6031	0.0004	0.2832	0.0263	0.0011	0.0002	<0.0001
	October	0.0000	0.0273	0.2376	0.0001	0.0459	0.0195	0.001	0.0000	<0.0001

Country and Regional Policy Developments

European Community

Although the development of policies to deal with a range of emerging discard problems has received considerable attention within branches of the U.S. government, it is by no means an issue unique to the U.S. A recent communiqué from the Commission of the European Community to the Council of the European Community (Commission of the European Community 1992) noted:

> The quantity of fish discarded into the sea is substantial, since although the practice varies considerably, it is followed by virtually all vessels. The seriousness of the problems to which it gives rise would be assessed in objective terms, whether as losses of a certain amount of a raw material, economic losses for the sector, or ecological impact, particularly in terms of the protection of biological resources and the environment. Further problems include compliance with Community rules, which makes discarding compulsory, and with Norwegian legislation, which partially prohibits it, albeit in different circumstances.

This paragraph of the report raises the Community's awareness of the problem's severity. The report concludes:

> The problem of discards is of such importance and its repercussions of such gravity that drastic solutions must be sought now, at a time when the increasing scarcity of stocks is of great concern to Community fisheries and when the ecological damage, true or imagined, caused by fishing is raising more and more questions. The Commission acknowledges that some of the existing Community rules contain drawbacks. The search for solutions will only be possible, however, if all the forms of and reasons for discards are considered.

European managers have imposed a number of area closures, such as the "pout box," which bans the Danish industrial fleet from fishing an area of the North Sea to prevent capture of small haddock and cod (Amos 1992). A more comprehensive policy is expected to evolve within the European community which has only recently attempted to undertake an in-depth review of the magnitude and scope of the problem. At the Newfoundland Mobile Gear Selectivity Workshop (1992), Robertson, for example, states:

> The United Kingdom Minister of Fisheries and the European Fisheries Ministry[39] are working hard and effectively towards helping to improve the fishing industry by introducing more selective gears. The fishing industries of Europe are also working hard to this end. There is a better awareness by everyone working in and serving the industry that more selective gears are required.

Nevertheless, later in the Newfoundland workshop, Ashworth (1992), a fishing gear technologist, noted that "we in Europe have the situation where the industry puts forward ideas, not always listened to and usually ending up in fighting and disagreeing with administrators and scientists, and also ourselves internally within the industry." Ashworth's conclusion is that not much progress is made, a somewhat different perspective from that presented by the government.

Norway

In recent years, Norway has made a major effort to use various gear technologies to reduce mortalities on non-target species. The Nordmore Grate[40] (Amos 1992), for example, is now mandated for use in Norwegian shrimp fisheries and several other areas of the world (see Chapter 9 for details of Nordmore grate development). Recently, Norway also adopted a discard ban with the intent of minimizing catches of undersized fish. The ban is expected to (1) prevent the loss

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[39] For a detailed discussion of various bycatch-discard regulatory actions taken in the Northeast Atlantic, see Chapter 7.

[40] A metal grate system placed in the upper throat of the trawl to separate shrimp from roundfishes.

of usable raw material, (2) upgrade scientific data on the basis of which TACs are calculated, taking all fish caught into account, and (3) achieve better conservation, since all fish caught count against the quotas (Commission of the European Community 1992).

In contrast, the European Community has approved a ban whereby "it is prohibited to retain on board or to land catches from stocks for which TACs or quotas have been fixed or reached, except in six special cases." The two opposing approaches perhaps reflect the complexity of the problem and differing perceptions as to how best to reduce losses due to discards.

Canada

In Eastern Canada where cod and other groundfish stocks have plummeted, the Honorable John C. Crosbie, Minister of Fisheries, has proposed a comprehensive plan to protect juvenile fish. Under consideration by the Minister are (1) gear restrictions, including mesh size and mesh types, as well as hook size for longliners, (2) implementation of an Atlantic-wide use of separator trawls and selector grates, and (3) new conditions of license requiring proper use of fishing gear and an expanded definition of illegal gear. Andrew Duthie (1992), Chief of Fisheries Technology for the Canadian Department of Fisheries and Oceans, notes that "as a result of current serious resource problems[41] with Canadian fishing gear selectivity, initiatives designed to allow for the escapement of immature fish and non-target species have been identified as an area of high priority within the fishery."

New Zealand

Discard management has also become an integral component of the Individual Transferable Quota Management Regime in New Zealand and Australia. In reviewing the New Zealand fishery policy, Gordon (1992) notes:

> Bycatch reduction touches on every aspect of the management and conservation regime: goals; objectives; understanding of the problems for which there appear to be solutions; acceptance of problems for which solutions appear partial or currently unavailable; legislation; regulations; enforcement by the agency; compliance behavior of the industry; the industry complex and its prosecution of the fishery from harvest to market; research and development both in biological stock and in gear technology and its behavioral interaction with the stocks under different conditions in time.

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[41] Cod and groundfish fisheries of the region have been severely constrainted as a result of a sharp decline of these species.

Central West Africa

Studies undertaken in the late 1970s by Senegal, Ivory Coast, Congo, and Nigeria have confirmed the need to increase mesh size for the trawl fisheries of the region. These studies ultimately led to a recommendation of a minimum mesh size of 60 mm for the exploitation of demersal fisheries. Garcia and Poinsard (1987) note:

> Implementation and enforcement of this mesh size is, however, far from being realized even in areas where it is clear that the mesh size of 60 mm (stretched) is still smaller than that which would give best bycatch results.... This problem is now being studied, but progress will be slow because of the far-reaching political and economic consequences of any decisions.

In recent years there has been an expanded effort by West African countries to gather data and come to grips with the extensive bycatch and discard problems of the region (McGlade, pers. comm.).

East Africa

Although throughout much of the north temperate zones, nations have evolved fishery policies designed to reduce bycatch discards, in many African countries, government polices have concentrated on development of market opportunities for bycatch species. For example, in Mozambique efforts to dry and salt fish taken in the shrimp fishery date back over a decade (Jensen 1985). Further, at a FAO-Expect-Consultation on fish technology in Lusoha, Zambia, Jenson notes the development and use of six to seven-meter vessels with small inboards that transfer bycatch from at-sea vessels to shoreside markets. This transfer permits retention and use of bycatch that formerly had been discarded. Razafindralambo (1985) reports on other East African efforts recently utilizing gears and methods which avoid or reduce excessive bycatch.

Southeast Asia

Pauly and Neal (1985) discuss a number of problems involving fish/shrimp interactions, including bycatch, occurring in Southeast Asia and the technological, biological, and social difficulties underlying solutions to such problems. The authors note early bycatch studies were conducted largely by Indonesian scientists, but since the mid-1980s, a wide variety of bycatch problems have been studied by a number of Southeast Asian countries, including India, Malaysia, and Thailand.

Middle East

In the late 1970s, FAO (Grantham 1980) recognized the need to assess the quantities of bycatch and discards in the Middle East countries bordering the Arabian Sea. In order to promote more efficient utilization and rational exploitation of regional fisheries, an assessment was undertaken to determine the availability and composition of bycatch taken in the Gulf area. The study also involved an assessment of the feasibility of bycatch preservation and possible utilization of bycatch for human consumption and other purposes. The largest quantities of bycatch in the sea were reported for Iraq and Iran, at that time the largest fish producers of the eight nations surveyed (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates). In recent years, bycatch and discard policies are less clear, with the exception of Oman's, where a significant effort to establish bycatch and discard levels was undertaken in the late 1980s. As the commercial trawl fisheries off Oman developed, specific company quotas were established. These quotas referred to total catch amounts, not just retained catch. Thus, it became important to develop a program to obtain information regarding levels of discards. Subsequently, an onboard observer program was established which led to a significant increase in the available information concerning the community of fishes harvested and discarded by local fishermen (Hare 1992).

UNCLOS Provisions

The United Nations Convention on the Law of the Sea contains a separate provision dealing with bycatch and discards, that is, coastal states in taking conservation measures for target species "shall take into consideration the effects on species associated with or dependent upon harvest species with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened."

Burke (1992) notes the U.N. standard for bycatch seems to be higher than for target species in that the UNCLOS aim for target species is to prevent endangering them, while for discard species the aim is to prevent even threatening them. In other words, one might threaten target species, but not discarded species. However, the biological viewpoint is not that clear and the two situations may be roughly equivalent. Article 65 of the UNCLOS treaty on marine mammals declares that nothing in the Article on the EEZ "restricts the right of a coastal state or the competence of an international organization, as appropriate, to prohibit, limit, or regulate the exploitation of marine mammals more strictly than provided for in the past." It would seem that a nation may completely prohibit any take of marine mammals, including incidental takes, for reasons other than imposed threats to a population.

U.N. Involvement with High Seas Driftnetting

Development of U.N. bycatch policies like those in the U.S. was also closely linked to the high seas driftnet issue. In late 1990, the U.N. was drawn into the high seas driftnet conflict, primarily on the basis of the "dirtiness" (levels of discards) of this type of gear (Miles 1992b). The 1989 U.N. General Assembly (UNGA) Resolution No. 44/225 was crafted in a manner that in order for the fishery to continue, the fishery states would need to show there were no unacceptable impacts on affected species and effective conservation measures were in place.[42] However, the analyses of the scientific data required to address such potential impacts and development of an appropriate conservation regime were never realized. Concerns for immediate action to prevent perceived unacceptable ecological risks outweighed interest in examining closely the data being developed from the observer program and results of further research.

The mandate to the nations involved in the high seas driftnet fishery demonstrates to the world community that no unacceptable ecological impacts occurring were insurmountable, as would perhaps be the case involving most fisheries conducted within the EEZs of coastal states. Thus, less than two years after the initial resolution, the U.N. framed its 1991 resolution recommending termination of driftnetting arguing that "in accordance with Paragraph 3 of Resolution No. 44/225, some members of the international community have reviewed the best available scientific data on the impacts of large-scale pelagic driftnet fishing and have failed to conclude that this practice has no adverse impacts which threaten the conservation and sustainable management of living marine resources."

Burke (1992) notes the important significance of these findings is that they introduce into fisheries the "precautionary principle," that is, in case of doubt about the consequences of an activity, apply regulations. It is further pointed out the key question about such a principle is whether it addresses a risk of such high order that it warrants precautionary action. We have no intention of attempting to enter into this dispute; it would seem the world community has at least tentatively passed judgment on these issues. We note, however, the consequences of fishing in areas beyond national jurisdiction may well be held to a measure of proof regarding potential ecological impacts difficult for managed fisheries within national jurisdictions to provide.

What cannot be argued is the discard issue. Associated policies have escalated to the highest level of world government and "the implication of bycatch mortalities on protected resources and societal perception of wasteful practices can

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[42] The UNGA Resolution contains a principle that reverses the normal burden of proof required by management agencies and mandates that conservation measures be in place before the available scientific data supporting specific actions is available or before fishing may begin or be continued (FAO 1992).

no longer be ignored" (Murawski 1994; Martin 1992). Results of this study would seem to justify the international concern.

Cancun Declaration

The International Conference on Responsible Fishing held in Cancun, Mexico, in May 1992 (Declaration of Cancun) pointed to the "vital need for fishing to continue and develop within a comprehensive and balanced system under the concept of responsible fishing." The Conference outlined two goals for coastal states in respect to incidental catch and discards:

1. In the design and subsequent introduction of new fishing gear and practices, states should take into account qualified assessments of impacts on the sustainability of fisheries, giving due consideration to the specific biodiversity of different fishing areas.

2. States should promote systematic use of selective fishing gears and practices that minimize waste of catch of target species and bycatch of non-target species.

The Cancun Conference also addressed non-tariff barriers to trade that can be tied to the bycatch issue. The U.S., in attempts to extend the influence of national policies concerned with conservation and environmental policies, has frequently used and threatened to use trade sanctions to force other coastal states to adopt fishing methods and gear restrictions which would reduce levels of incidentally caught marine mammals, turtles, and seabirds. In 1992, the U.S. Congress adopted the International Dolphin Conservation Act (IDCA), authorizing embargoes on tuna products imported from Mexico, Venezuela, and Vanuatu, as well as "intermediary" nations, although it was not until 1990 embargoes were imposed on those countries and then as a result of a court order (Young et al. 1993; High Seas Driftnet Fishing Hearing before the Committee on Commerce, Science, and Transportation, U.S. Senate 5884, To Require the President To Impose Economic Sanctions Against Countries that Fail To Eliminate Large-Scale Driftnet Fishing). Concerns over U.S. efforts to impose its "conservation measures" on other nations (Freeberg 1992) led Mexico to request the convening of an international panel that contributed to a discussion of trade sanctions for environmental purposes and spawned a lengthy declaration regarding the use of trade sanctions on the part of the Cancun Conference:

> States recognize that environmental policies should deal with the root causes of environmental degradation, thus preventing environmental measures from resulting in unnecessary restrictions to trade. Trade policy measures for environmental purposes should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade. Unilateral actions to deal with environmental

> challenges outside the jurisdiction of the importing country should be avoided. Environmental measures addressing international environmental problems should, as far as possible, be based on an international consensus. Domestic measures targeted to achieve certain environmental objectives may need trade measures to render them effective. Should trade policy measures be found necessary for the enforcement of environmental policies, certain principles and rules should apply. These could include, *inter alia*: the principle of non-discrimination; the principle that the trade measure chosen should be the least trade-restrictive necessary to achieve the objectives; an obligation to ensure transparency in the use of trade measures related to the environment and to provide adequate notification of national regulations; and the need to give consideration to the special conditions and developmental requirements of developing countries as they move towards internationally agreed environmental objectives.

The report of the UNCED also addressed discard waste issues. Under Agenda 21, Chapter 17, Section 46 dealing with ocean management, the report promotes the development and use of selective fishing gears and practices that minimize waste in the catch of target species and minimize bycatch of non-target species (a repeat of the Cancun Declaration). The report further notes countries should (1) ensure fishing activities by vessels flying their flags on the high seas take place in a manner minimizing incidental catch and (2) take measures to increase the availability of marine living resources as human food by reducing wastage, post-harvest losses, and discards.

Finally, international involvement with bycatch issues and expanded national efforts to cope with discards is further reflected in the diversity of papers presented at the recent (1992) World Fisheries Conference in Athens. Papers by Buck, Suwanrangsi, Probkev, Morrissey and Robles, Wilson and Weeks, Pellegin, DeAlteris and Castro, Lien, Nielson and Lien, and Hartmann et al. discussed various aspects of the discard issue.

Chapter Summary

In a matter of a little over forty years, the attention and focus of world fisheries has radically changed from development and maximizing the sustainable use of the ocean's living resources to global concern over extensive overfishing of target species, biological waste, and the potential impact of fishing practices on non-target species and ocean ecosystems. Within the past decade, a plethora of studies has directed attention to discards and associated economic and biological losses. Although documentation of discard levels for many world fisheries is far from complete, the implied levels of discard mortalities and associated fishing-related losses, as estimated in our study, are large, and impacts are shown to be significant in certain regions. National programs directed toward reducing discard

levels and associated mortalities are beginning to take shape, but considerable effort must be made to clarify national and international goals and to examine management strategies and technological solutions which will reduce incidental harvests of discards of overfished and threatened species and allow small, juvenile fish to survive to become a part of the fish harvest.

National and international policy to deal with bycatch and discards has evolved at a rapid pace in the past decade and is in a continuous state of metamorphosis. Within many developed and some developing countries "ethics" or "philosophical" issues concerned with the killing or taking of marine mammals and other sea life has added a new dimension to national resource management and has begun to play a major role in the evolution of discard policies.

As governments begin to examine alternatives to address the world discard problem, the formulation of an internationally agreed-upon set of goals and methods of quantifying discards and their impacts will be important steps in the future development of marine resources management policy. The goals should include a clarification of conservation, socio-economic, and ecological objectives and their respective priorities.

CHAPTER 9 SEARCHING FOR SOLUTIONS

Questions Confronting a Search for Discard Solutions

In looking for solutions aimed at reducing levels of catch and mortality for species or sizes and sexes of species that are discarded, several important questions need to be addressed:

1. Why are particular species or sizes and sexes of certain species caught and discarded?

2. What quantities of different species (sizes and sexes) are discarded?

3. What is the ultimate fate of discards?

4. What are the benefits of present discarding practices and what are their costs to the fishermen and society? Who causes the problems, who benefits from current practices, and who would benefit from the solutions?

Answers to these questions are necessary ingredients in formulating national goals and strategies to characterize and address identified impacts. Once these questions have been addressed and goals and priorities have been clarified, a range of options (potential solutions) can be considered to reduce either the bycatch levels or the mortality imposed on discards. In this chapter we attempt to address the factors that need to be evaluated when searching for options to reduce discard levels or the impacts of discarding. Potential solutions reported in the literature are also discussed.

Why are particular species or sizes and sexes of certain species caught and discarded?

Authors who have studied bycatch and discards in some detail have identified a wide spectrum of reasons fish and other marine life are captured and then discarded (Murawski 1991, 1992, 1993; Pikitch 1991, 1992; Northridge 1991a, 1991b; Saila 1983; Murray et al. 1992). Reasons identified by scientists can be categorized as follows: (1) physical-biological interaction, (2) economic, and (3) legal. We have added personal value considerations to this list. These categories are similar to the origins and causes of discards discussed in the bycatch report of the Commission of European Communities (1992).

The physical and biological reasons unwanted species are captured lies in the facts that (1) target and non-target species co-inhabit the ocean space coming under the influence of the harvesting systems employed, (2) the species encountered may behave differently to the fishing gear, and (3) the methods of gear deployment and

the physical characteristics of the gear deployed are, for the most part, not species- or sex-specific and, in varying degrees, not size-specific. Thus, if passive gears are deployed using bait to attract fish, a variety of target and non-target species in the area under the influence of the bait may be attracted to the gear. If passive driftnets are used, all species and sizes of species which are within the range of sizes selected by the gear that cannot detect the gear are subject to capture. If, on the other hand, active gears like trawls or seines are deployed, the spectrum of species in the path of the trawl or encircled by the seine are candidates for capture and discard.

Of course, the size of hooks used, tunnel characteristics in pots, mesh size, geometry of the gears, and many other factors can vary the outcome of a gear component. Few gears and operational modes are always "clean." Instead, the level of unwanted fish taken by gear types will vary considerably, depending on how gear is rigged and when and where it is deployed.

Investigators examining the basis for the capture and discard of marine fishes deal in some depth with underlying economic issues, and some note all discarding directly or indirectly involves economic issues. There is undoubtedly a good deal of truth in this observation. Economic factors underlying discards can involve discard of (1) species for which no reasonable market exists, (2) sizes or sexes of species not acceptable to markets, (3) physically damaged fish, (4) fish generating problems for other species within the catch (slime, abrasiveness, etc.), (5) species which deteriorate rapidly, (6) availability of space and refrigeration on vessels, and (7) high-grading.

High-grading refers to the discard of one species of fish while keeping a higher-value species, or more frequently the discard of certain sizes of fish in favor of sizes receiving higher prices (Gillis et al. in press). In reality, however, high-grading encompasses the entire fishing practice of selecting target species, areas, and sizes and sexes of species. It begins with the selection of a gear type and is an integral decision process throughout the fishing operation, including the selection of fishing areas, depths, and temperatures. Fishermen most often optimize their economic goals in selection of gear, operational modes, and on-deck selection of fish to be retained. This selection leads to a maze of fishing patterns targeting on both high- and low-value species. Most gear types will at times have high bycatch rates. The exception may well be those fishes predicated on high-volume production, such as clupeoid fishes for meal or roe and a few very selective gears like squid light fisheries. In such fisheries discards are rare (Guillory and Hutton 1982). The willingness to sort through large quantities of fish in order to select a small catch appears to be directly related to the value of the target catch, as in the shrimp fisheries where large amounts of fish are sorted through to retain a relatively small quantity of target catch.

Murawski (1994), in his examination of discarding groundfish in the Gulf of Maine, identified three major reasons fishermen discard: (1) no market, (2) too small, and (3) poor quality of catch. "No market" and "too small" were by far the

dominant reasons identified for discards (Figure 14). These results may be compared to those of Pikitch (1991) who found the most common reasons given for the discard of five species of rockfishes taken off the West Coast of the U.S. involved (1) minimum acceptable market sizes, (2) high-grading, (3) trip quota for species already exceeded, and (4) a variety of "other" factors (Figure 15). Laevastu and Favorite (1988) note similar problems, but add the issue of prohibited species.

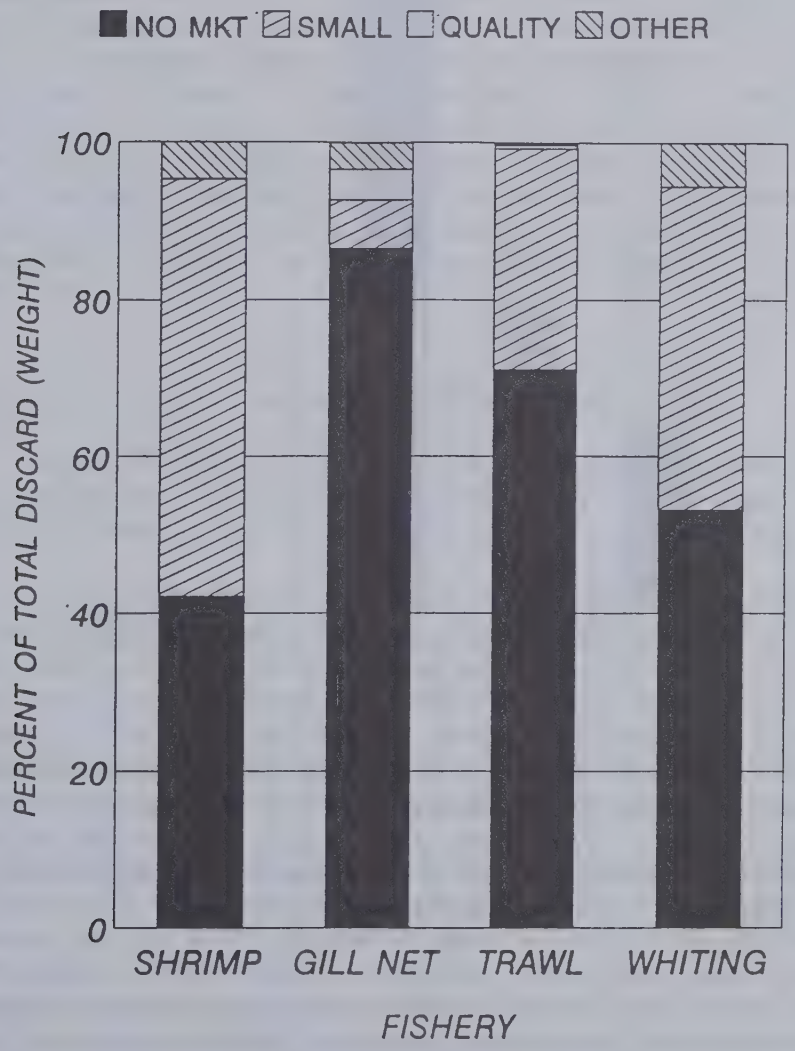

Figure 14. Reasons for discards in four Gulf of Maine groundfish fisheries from sea sampling trips conducted in 1991. Reasons are: No Mkt = species for which no market existed, Small = fish smaller than minimum legal size or minimum market size, Quality = fish of poor market quality, and Other = a variety of other reasons for discards. Source: Murawski 1993

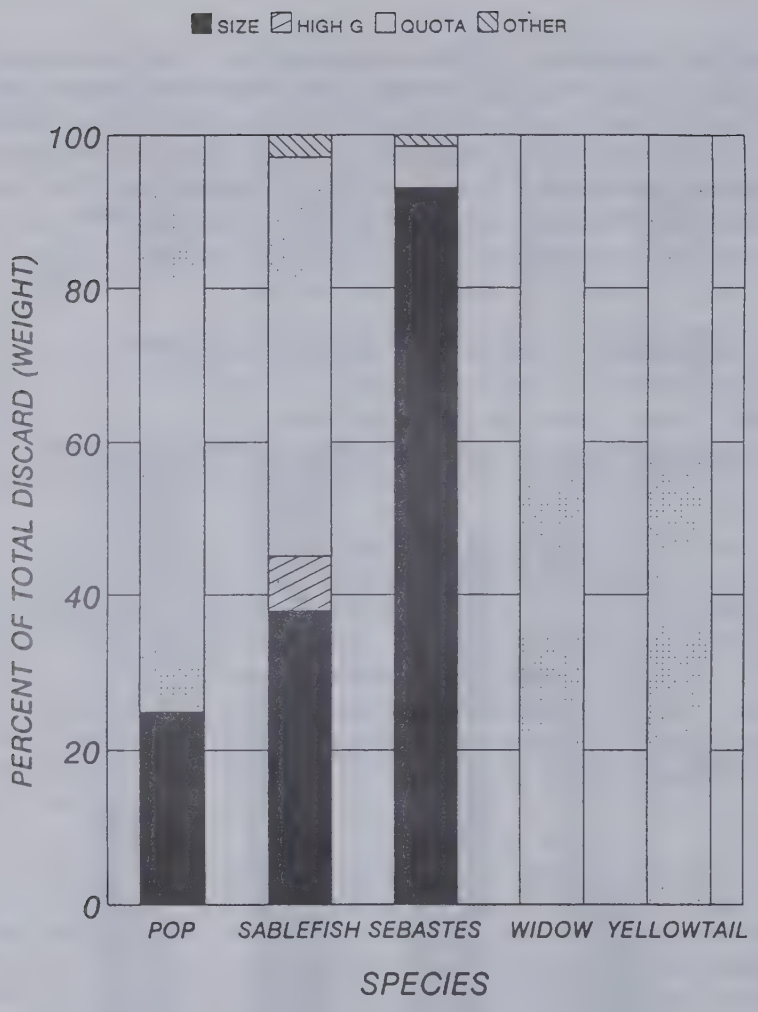

Figure 15. Reasons for discards in five West Coast groundfish fisheries from sea sampling trips conducted in 1991. Reasons are: Size = below minimum acceptable market size, High g = high grading of species catch, Quota = trip quota for species already exceeded, and Other = a variety of other reasons for discards. Source: Pikitch 1991.

One of the most controversial aspects of the bycatch issue within elements of the commercial fishing community is the mortality impact on discards of species caught by one fishery which are the target of another fishery.[42] This problem frequently occurs when regulatory regimes require that for certain species, capture and retention be limited to a specific gear type. Thus, all captures of the species by other gears must be returned to the sea regardless of whether they are dead or alive.

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[43] This problem differs between regions and is a growing problem in North America and Europe.

Murawski (1994), commenting on this issue, states that "the incompatibility of regulations with the reality of the species mix contributes to the discard of economic species."

We have added to our list of factors governing why species are discarded the category "personal preference" in that a considerable amount of fishing does not involve commercially structured operations. U.S. recreational fisheries frequently generate a significant discard. Discarding in recreational fisheries generally reflects a person's decision not to keep the catch because the species captured is considered undesirable for a variety of reasons--the catch is too small, damaged, or illegal to retain. Thus, recreational fishing, like commercial operations, involves degrees of "high-grading." A recreational fisherman with a limit of two fish may choose to discard a number of fish in order to catch and retain a larger fish of the same species. Selection of fish among a mixed catch also occurs in subsistence fisheries. In such instances, choices among species are frequently personal preferences which may vary sharply between fishermen and between regions (NRC 1993; Andrew and Pepperell 1992). Personal preferences may also involve discards in subsistence fisheries.

What quantities of different species (sizes and sexes) are discarded?

Fisher (1992) notes the formulation of any bycatch program must have observable scientific data as a basis for understanding discard impacts and for structuring effective management or technical solutions.

Of course, it has been the objective of this study to clarify the character and magnitude of discards occurring in various world fisheries. Although the number of observations on discard rates in various fisheries has increased in a dramatic manner over the past decade, comprehensive documentation regarding the biodiversity of species taken and discarded, as well as the biological, economic, and ecological impacts of discards, is infrequent. Even among datasets which provide such information, few are based on sampling extended over seasons and between years.

Murawski (1992) notes the collection and documentation of discard rates to date has involved use of at-sea observer data. Because of the expense, spatial limitations, and other factors, few fisheries have been sampled adequately and in a random manner. When observer coverage is low and spotty, crew behavioral patterns may bias the data. Murawski (1992) observes:

> The skipper and crew always know they are being observed, and there may be a strong subconscious desire on the part of fishermen to clean up their act.... Scientifically supportable discard rates will require representative sampling of trips with which to characterize the fleets as a whole while observing a sufficient number of trips so that normal trip-to-trip variability can be taken into account.

The only major world fisheries where an observer program now provides such comprehensive fleet data are the trawl, line, and pot fisheries for demersal fishes off Alaska and the tuna purse seine fishery of the ETP. In Alaska, the cost of this extensive observer program is borne by the fishing vessel owner and in the ETP tuna fishery by nations or vessel owners.

The types of statistical information required to assess the consequences of discards in relation to stated management goals are for the most part identical to those collected for harvested species, that is, species diversity, numbers, weights, sizes, sex composition, abundance trends, and life history features. For exploited marketable species, discard information forms the basis to quantify the actual catch. Catch = landings by all vessel and gear classes + discards of all vessels and gear classes. On the other hand, the catches of unmarketable species can only be derived from the sum of the discards of vessels and gear classes fishing a particular stock/area, plus fish which are landed but not purchased[44] (no record of landing).

Saila (1983) discusses in some detail the procedures for discard estimation, including the character of observations and estimating procedures. Data collected should allow investigators to estimate:

1. Total quantities of various species discarded
2. Size distribution of discard species
3. Percent of discard of total catch (numbers and weight)
4. Biodiversity of species discarded
5. CPUE of discarded species

Bycatch data may form the single most important database on the species distribution and abundance of unexploited species, as well as serve as an excellent source of information regarding species life history and behavior characteristics. Further, such data may contribute significantly to the understanding of species complexes and species interactions within different ocean ecosystems.

What is the ultimate fate of discards?

Chapter 1 of this report summarizes in some detail information on the fate of discards during fishing operations. There is general agreement among most fishing scientists that most, if not all, of the roundfish taken (cods, hakes, pollock, croakers, rockfishes, snappers, groupers) die as a result of distended air bladders and the inability to sound. Nevertheless, portions of the catches of flounders, sharks, some invertebrates, and other species not affected by rapid changes in depth or temperature may survive. Survival of discarded species may be sharply influenced by the nature of the gear used, the manner in which it is deployed, the

[44] Buyers may refuse to accept catches because of their quality or because the catches exceed processor needs.

time fished, the size of the overall catch, the composition of the catch, and the handling of the catch after capture. Thus, for some species, reduction in the discard mortality rate can be significantly effected through rapid return of the unwanted catch to the ocean, shortened fishing time, reduced catch levels, and improved on-deck handling procedures.

Knowledge of discard mortality rates is of importance in determining the consequences of catch-and-release strategies and whether or not realistic opportunities exist to improve the survival of discards. In a broader context, the fate of discards may also be an important question in terms of ecosystem impacts (Bricklemyer et al. 1989/1990). If solutions rest on the improved survival of discards, then the extant levels of discard mortality must be verified and potential actions to increase survival investigated.

What are the benefits of present discarding practices and what are their costs to the fishermen and society? Who causes the problems, who benefits from current practices, and who would benefit from the solutions?

Dealing with these questions in any detailed manner would in itself be the basis of a major treatise. To begin with, societal values differ between users, and many of the values associated with biological and ecological attributes and esthetic issues will be difficult to quantify. Nevertheless, this set of questions will ultimately require attention if discard management is to be formulated on a composite of well-thought-out bioeconomic and ethical values.

Under historical practices, fishermen must have assumed there were no benefits in altering fishing activity operational patterns or technology, in order to avoid discards. In essence, there were few, if any, perceived economic or other advantages in avoiding bycatch. The recent evolution of regulatory regimes in many regions of the world to deal with bycatch/discarding has obviously already altered fishing practices and confronted the fishing industry with incentives for change--even in the absence of more quantitative evaluation of benefits and costs. As we begin to identify the costs of change, the character of benefits, and those responsible for the problems, the beneficiaries will become more clear. In the interim, managers are likely to make a number of short changes without fully recognizing how such changes will impact biological, economic, ecological, and other societal goals.

Solutions to Current Discard Problems

The character and spectrum of solutions to discarding will depend in part on the nature of the problem being addressed, and on local fisheries and environmental policies. If the driving policy is rooted in achieving conservation goals, the solution may be confined to reduction in the bycatch of impacted species. Regulations proposed to address conservation problems aggravated by discards may

differ significantly from those attempting to address issues of waste or ethical concerns. Solutions to economic transfer losses may depend on regional policies concerned with the losses imposed on one group vis-à-vis the gains resulting from added production of the group responsible for the bycatch (Amjoun and NRC 1991). In such cases, historical fisheries have been given protection from discards occurring in developing fisheries.

Regardless of the character of the discard problem, only a few functional alternatives are available:

1. Catching fewer numbers of the species or sizes and sexes of the species comprising the discard

2. Reducing the mortality of the species being discarded

3. Using a greater spectrum of the species or sizes of species caught and discarded

Over the past decade, various strategies have been used to attempt to deal with bycatch and discards, including (1) instituting incentives and disincentive programs, (2) making the use of certain gears in certain areas illegal, such as the pout box, (3) completely banning the use of a particular gear technology, like high seas driftnets, (4) permitting continued use of a gear type but regulating its discard catch efficiency, such as enforce mesh, hook, or escapement panel size restrictions, (5) establishing fishery-level discard quotas, as in the Bering Sea which has prohibited species catch quotas, and (6) utilizing time/area closures. In many cases, market opportunities for bycatch species have also been expanded, thereby increasing the retention and landings of catch fractions previously discarded.

Unfortunately, as witnessed by the bycatch and discard data presented in Chapter 1 of this volume, the aforementioned strategies have not yet addressed a majority of the bycatch and discard problems. Great quantities of non-target finfish and shellfish are being removed by global fisheries. On average, 0.32 mt of fish are estimated to be discarded into the sea for every metric ton landed for human consumption and other uses. In many cases we do not understand the implications of these removals well enough to claim they are harming biological or ecological systems. Nevertheless, there is a growing concern that users should search for those technologies, operational patterns, and management strategies which reduce bycatch to its lowest possible level while permitting the industries to produce protein needed to feed human populations. Such a goal (Murawski 1992; Alverson 1992; Commission of the European Communities 1992) has been suggested within the rationalization of the bycatch problem.

Gear-based Selectivity Solutions

Outlawing use of gear types for specified fisheries

Reduction in discard levels through regulations making the use of certain gear types illegal, like high seas driftnets, or setting quotas on the quantities of bycatch to be taken, such as for North Pacific groundfish, can quickly terminate discard problems or limit the extent of discard mortality. Such regulations, however, may impose significant economic losses on those being regulated, reduce the availability of fish supplies, and increase operational costs of traditional users. From the standpoint of fishing interests, a preferable solution is the reduction in the capture and discard of species or sizes of species through use of more selective fishing gears, time/area fishing strategies, or vessel incentive programs.

Reduction in discards using gear selectivity

From a historical perspective, fishery managers have attempted to minimize pre-recruit mortality through use of mesh sizes in trawls, seines, pots, and traps that release a significant number of the undersized target species (Armstrong et al. 1990; Dawson 1991; Caddy 1989). The functional aspect of gear selectivity is based on the escapement opportunity provided by the use of webbing, hooks, and pot tunnels of different sizes and shapes.

A comprehensive list of references concerned with selectivity of various fishing gears and methods of research in this field has recently been prepared by Prado (1992) for the FAO of the United Nations. The document is organized to examine selectivity issues associated with different fishing gears and to compare gears and research methods. Further, the report organizes selectivity references in terms of species and regions. A narrower and somewhat earlier review of selectivity of gillnets has been published by Hamley (1975).

Although considerable progress in the reduction of the capture of undersized fish can be attributed to increasing mesh sizes and other gear selectivity regulations, reduction in the overall quantity of bycatch has been offset by (1) increasing global fishery pressure (Alverson and Larkin 1992), (2) differentiated growth rates of target and non-target species, (3) the failure of mesh regulations to deal with the capture of many unwanted species, (4) the ease of altering gear at sea and avoiding gear selectivity regulations, and (5) failure, at times, of the fishing industry to be willing to adopt fishing methods proven to be more selective.

Shrimp mesh selectivity studies, as with numerous species of fish, have been carried out with the objective of allowing greater escapement of undersized shrimps (Chian et al. 1988; Kendall 1990; Valdemarsen 1989; van Zalinge et al. 1979; Clark 1960; Lemcke 1986; Simpson and Perez 1975; Tokai et al. 1990). Similarly, a wide variety of selectivity studies has been undertaken on dredges, pots, traps, and gillnets (Prado 1992). However, unless required by law, these experiments

were only marginally successful in reducing the capture of undersized shrimp and other bycatch.

Attempts to overcome some problems associated with net selectivity and rigging of the gear of active fishing nets, such as trawls and seine, have over the past several decades been addressed by the introduction of "square mesh," single-mesh codends, knotless and colored webbing, escape panels, and the manner in which the webbing is secured to riblines (Anon. 1988; Anon 1990; Averill and Carr 1987; Averill 1990; Bohl 1987; Bohl and Dahm 1991; Casey and Warnes 1987; Cooper 1989; Dahm 1990, 1991; DeAlteris et al. 1990; Fonteyne and Robet 1988; Hearn 1988; Hickey 1988; Hillis et al. 1991; Innes 1989; Isaksen and Valdemarsen 1986, 1988, 1990; Larsen 1988, 1990; Larsson et al. 1988; Larsvik and Ulmestrand 1991; Pikitch and Bergh 1988; Robertson 1986; Robertson et al. 1986; Thorsteinsson 1989, 1991; Ulmestrand and Larsson 1991; Walsh et al. 1989).

These studies have tended to confirm findings that escapement from trawls is impacted by webbing shape during fishing operations, in particular the mesh size and shape in the upper portions of the codend. In general, selectivity studies show the catch of undersized fish can be minimized by (1) using larger mesh, (2) ensuring the codend meshes remain open during fishing, (3) minimizing use of chaffing gear, particularly in the upper portions of the codend, and (4) in some instances using square mesh nets. The advantages of square mesh and other techniques to ensure that webbing configuration is optimal for escapement largely address issues of size selection, and species-specific selection problems are only indirectly dealt with by these adjustments.

Reductions in discards based on differential species behavior

Since the problem of bycatch and discards has escalated over the past two decades and been acknowledged as a major management issue, greater efforts have been directed towards reducing bycatch by taking advantage of the differential behavior of the range of species subject to the fishing gears deployed (Adlerstein and Trumble 1992; Watson 1989, 1992; Marasco and Laevestu 1992; Rose and Williams 1992; DeAlteris and Castro 1992; Laevestu and Alverson 1992; Fernö 1992; Glass et al. 1992; Ye 1992; Robertson 1992; Suuronen et al. 1992; Toivonen and Hudd 1992; Tschernig et al. 1992; Wardle 1992; Valdemarsen and Mikalsen 1991; Urquhart and Stewart 1992; Wray 1992). Studies of species behavior may help with species-specific selection. For example, square mesh side panels to reduce the catch of haddock and whiting and the use of large ground-rope bobbers allow small cod to escape under the net.

Examination of the historic evolution of bycatch reduction in shrimp trawls reveals a series of approaches were taken, including (1) use of separating panels made of horizontal or vertical webbing with side- and/or top-oriented escape chutes (excluder funnels) for finfish, (2) use of electrical sorting trawls, and (3) use of rigged selector grids. The purpose and objective of the sorting experiments have

varied over time. In the early stages of panel trawl development, reduction in bycatch was seen as a means of reducing substantial sorting time. However, in the 1980s, conservation of turtles and reduction in the catch of certain species of groundfish became the primary basis for alternative gear designs (Andrew and Pepperell 1992).

Attempts to find solutions to discarding problems in shrimp fisheries based on behavioral differences date back almost thirty years. Boddeke (1965) and the FAO (1973), for example, reported on selective shrimp trawl attempts in Europe during the mid-1960s. These efforts were followed several years later by a series of experiments on the West Coast of the U.S. (Beardsley and High 1970). Experiments on the U.S. West Coast involving pandalid shrimp fisheries met with reasonably good results in terms of reduced catch of finfish species, although reports of the results are somewhat qualitative. Nevertheless, reduction in the target shrimp catch was perceived by fishermen to offset gains made in reducing the time required to sort. Further, lack of perceived conservation problems associated with the bycatch during the 1960s and early 1970s resulted in little continued industry or management agency interest in the adoption of the NMFS selective trawls.

During the 1980s, development of shrimp sorting trawls appeared to become contagious, and experiments using sorting trawls spread world wide (Anon. 1982; Anon. 1985a; Anon 1985c; Anon. 1988; Anon. 1991b; Ashcroft 1984; FAO 1985; Galbraith and Maine 1989; Griffin 1987; ICES 1985; Valdemarsen 1986; Isaksen and Valdemarsen 1986; Valdemarsen and Mikalsen 1991; West et al. 1984; Wardle and Hollingworth 1993; Wray 1990; Isaksen 1984; Karlsen 1983; Karlsen and Larsen 1988; Kenny et al. 1990; Larsen 1986; Schick 1991; Sea Fish Authority 1986; Sternin and Allsopp 1982). As a result, a variety of panel separators, funnel trawls, and other devices for sorting from bottom to top or top to bottom or having vertical separating qualities emerged for use in separating both northern and tropical species. Although many showed some promise, none seemed to attract wide-scale use by the world's fishing industry (FAO 1973; Watson et al. 1986).

U.S. experiments in the Gulf of Mexico shrimp fisheries were originally designed to examine use of netting panels to reduce finfish bycatch (Watson and Taylor 1990). Watson and Taylor (1990) note the early U.S. Pacific Northwest and European experimental shrimp separator nets were not effective in the Gulf of Mexico due to "filling and clogging of the separator panels." Further reduced catches of target species were reported. Thus, early designs evolved to deal with northern shrimp were not considered directly applicable to the penaeid fisheries of the sub-tropical and tropical regions.[45] Nevertheless, the concept of separator panels was not abandoned by U. S. investigators searching for a solution to the bycatch problem.

A significant effort was carried out by the U.S. National Marine Fisheries Service to address the Gulf shrimp fishery bycatch issue in 1974 (Watson and Taylor 1986).

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[45] A more recent study by Boddeke (1992) suggests investigators looking for solutions to penaeid shrimp trawler discard problems can take advantage of findings based on European experience.

The work resulted in a V-design vertical separator panel (Watson and McVea 1977). The "V" sorter net was reportedly designed to take advantage of behavioral differences between shrimp and finfish. In commercial tests, "V" separator trawls achieved from 60% to 80% separation of finfish. However, loss of target species catch and other problems led to the abandonment of the experiments in the late 1970s. Electrical trawls, which theoretically had considerable potential to resolve bycatch problems, never extended beyond a prototype. Major obstacles to acceptance of the electrical trawl system appeared to be the high cost of pulsar systems and conductor cables, as well as replacement costs of lost gear (Watson and Taylor 1986).

Perhaps the most significant event of the 1980s in the development of shrimp sorting devices in trawls based on behavioral differences has been the evolution of turtle exclusion devices (TEDs) in the U. S. (Watson and Taylor 1986, 1990; Anon. 1985d; Anon. 1991; Condrey and Day 1987; Conner 1987; Christian and Harrington 1987; McNeil 1964; Murphy and Murphy 1989). The first turtle excluder device resulted from the joint efforts of NMFS and Gulf commercial fishing interests (Watson and Seidel 1980). Since its development in the early 1980s, many types of TEDs have been developed and introduced to the fishing industry in response to federal and state regulations.[45] The search for effective TEDs ultimately led to a variety of net designs incorporating finfish separation based on behavioral differences (Harrington 1992). Unique to most TED nets (hard TEDs) has been the use of rigid bar separators, funnels, or soft flaps for elimination of the turtles (Figure 16). The efficiency of the TED has been high, and the elimination of finfish has reached 60% for some net designs.

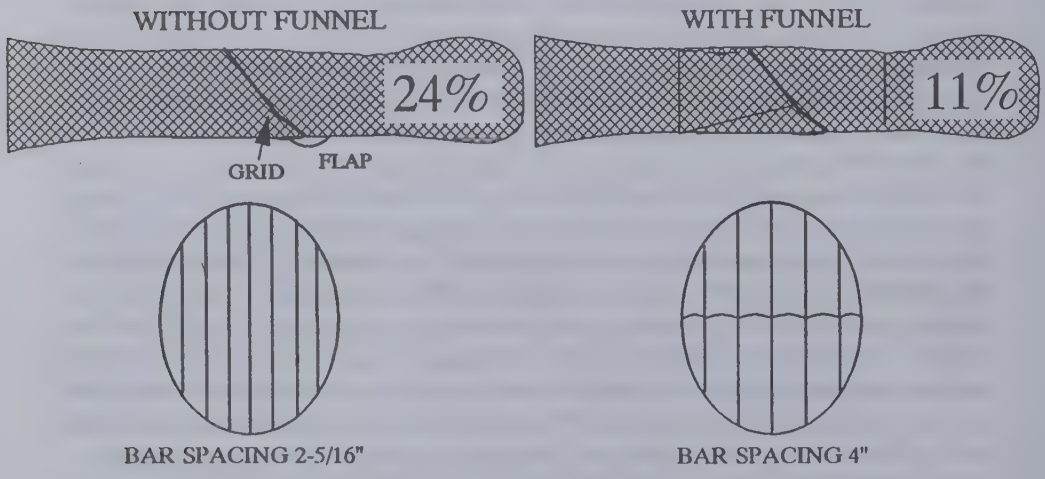

Figure 16. Basic hard TED and factors influencing bycatch reduction rates, i.e., bar spacing, funnel or no funnel, and flap size. Source: Harrington 1992.

[46] For TED nets to be legal, they must be certified by the U.S. NMFS and they must exclude 97% of the turtles encountered.

Regardless, they have not been easily accepted, and only a few types of nets are considered desirable by members of the industry (Harrington 1992). In an evaluation of excluder devices on shrimp catches in the Gulf of Mexico, Renaud et al. (1990) found significant differences between standard nets and nets rigged with TEDs, with lower shrimp and finfish catches occurring in the latter. The reduction in shrimp catch ranged from about 3% to 18%.

It is difficult to track whether or not the rigid grid concept used in TEDs gave inspiration to Norwegian researchers in their search for something better than panel separator shrimp trawls. Development of the rigid bar, solid grid separator trawl for pandalid shrimps--the so-called Nordmore grate (NG)--took place in the late 1980s and early 1990s (Olsen 1991; Isaksen et al. 1990, 1992). The rigid separator trawl seems to have solved many of the objections to separator webbing panels and to have increased separation efficiency, with only a small loss in shrimp catches. Separation success reaching 100% for cod and haddock older than 14-17 months and redfish older than 2-3 years has been reported (Isaksen et al. 1990). Again the NG has not always found strong support by fisheries, but its contribution to sorting out roundfish is generally accepted and supported by field experiments. Finally, the government of Norway has required its use in the country's northern shrimp fisheries, and the NG is being adopted in other world pandalid fisheries, such as Canada, Greenland, and the northern U.S. (Kenny et al. 1990; Isaksen et al. 1992). Results of shrimp sorting experiments using horizontal, vertical, and rigid spaced bars are provided in Table 40.

Table 40. Bycatch reduction (%) and proportional target species loss (%) from various shrimp sorting experiments by region.

Gear Type	Area Tested	Bycatch Reduction (%)	Target Species Loss (%)	Main Discard Species	Authors
PANEL NETS					
Horizontal	NW U.S.	77	>20	smelts, rockfishes	High et al. (1969)
Vertical	Norway	75-100	5-10	cods, haddocks	Isaksen (1984)
V Design Vertical	US Gulf of Mexico	38-45	6-12	croakers/porgies	Watson (1982)
TEDS					
Collapsible Steel Grid	US Gulf of Mexico	51	?	croakers/porgies	Watson et al. (1986)
Solid Fiberglass Grid	US Gulf of Mexico	53	?	croakers/porgies	Watson et al. (1986)
4" Georgia with Funnel	US Gulf of Mexico	11	?	croakers/porgies	Harrington (1992)
4" Georgia without Funnel	US Gulf of Mexico	16	?	croakers/porgies	Harrington (1992)
2.5" Georgia without funnel	US Gulf of Mexico	24	?	croakers/porgies	Harrington (1992)
Morrison	US Gulf of Mexico	31	?	croakers/porgies	Harrington (1992)
Lettich	US Gulf of Mexico	33	?	croakers/porgies	Harrington (1992)
Andrew 3" panel	US Gulf of Mexico	43	?	croakers/porgies	Harrington (1992)
Andrew 4" panel	US Gulf of Mexico	54	?	croakers/porgies	Harrington (1992)
NORDMORE GRATE					
Norway Experiment	Norway	100*	2.5	cod/redfish	Isaksen (1990)
Canada and East Coast N.A.	Newfoundland	75	67	cod	Anon. (1992)
	Nova Scotia	94	?	cod/redfish	Brothers (1992)
	Quebec	96	?	cod/redfish	Brothers (1992)

*For cod and haddock >16-17 cm.

The recent successes with TEDs and the NG have raised hopes that further tests using the grid concept or other behavioral-based strategies can lead to improvements in "bycatch reduction devices" (BRDs) for groundfish trawls (Anon. 1982). With the growing concern over discards, research on an increasing number of different styles of separator trawls for groundfish species has surfaced in the late 1980s and early 1990s (Anon. 1987a; Anon. 1987b; Anon. 1987c; Boudreau 1991; Campos 1991; DeAlteris et al. 1990; Hillis and Carroll 1988; Larsen 1990; Watson et al. 1986). These experiments have reported success in separating different species, with the separation of flatfish proving the most difficult. Mori (1986) reviews a series of experiments involved in the development of selective trawls in the North Pacific region. Success was reported in the reduction of chinook salmon catches while maintaining the catch rates of pollock. In a number of experiments, salmon and other non-target species catches were reduced. However, target species catches were also lower.

Despite some 30 years of experiments with sorting trawls and the use of net selectivity to reduce the capture of undersized target and non-target species, the adoption and continued use of such gears has been limited until recently. Such gears have frequently been adopted only in response to regulations. Although theory would suggest behavioral differences will ultimately lead to significant gains in separation efficiency, in most instances such advances occur over lengthy periods of experimentation and have associated costs questioned by those being asked to adopt new systems. These costs must ultimately be weighed against the assessed damage of bycatch, but the apparent success of the NG and its adoption as a required fishing method in several areas of the world is encouraging.

By far the bulk of the fishery literature concerned with fishing gear behavior experiments directed toward solving discard problems is concerned with shrimp and bottomfish trawls. However, a small number of interesting studies associated with other gear types shows fisheries continued progress toward solving bycatch and discard problems. Selectivity studies on longline hooks have shown that a reduction in the small fish catch can be achieved by adjusting hook size (Yetman et al. 1991; Bjordal 1989), while studies by Løkkeborg (1990) suggest reduced catch of undersized cod can be achieved by using artificial bait. In this regard, the reduction in small fish (cod) in line fisheries has been reported to be attributable to increased bait size (McCracken 1963; Johannessen 1983; Ralston 1982). However, Løkkeborg (1990) suggests the selectivity may also be a function of discriminating between the different shapes of natural and artificial baits and other feeding behavior phenomena. Løkkeborg and Bjordal (1992) conclude hook size and bait are the major selective characteristics of line gear during fishing in any particular location.

An interesting solution to a bycatch problem involving seabirds has recently been reported by Løkkeborg and Bjordal (1992). Fishermen using longline gear off the coast of Finnmark, Norway, frequently encounter seabirds which attempt to

remove bait from the hooks as the gear is set. This results in a significant bait loss and, at times, bird mortality. A simple bird "scarer" consisting of streams of yellow tarpaulin attached to the mainline by swivels at intervals of 5.5 meters was tested. In four skates (200 hooks/skate), the bait loss was 26.3% and 13% for mackerel bait and squid, respectively, using the scarer, while tests without the scarer resulted in 69% and 18.2% bait loss, respectively. No birds (fulmars) were taken when the scarer was used, while three birds were captured when the scarer was not employed. Similar techniques have evolved in Australian fisheries (Anon. 1991a, 1991b, and 1991c).

A variety of experiments using acoustic modifications to drift gillnets has been designed to attempt to reduce marine mammal catch (Dawson 1991a; Danns 1991; Snow et al. 1987), but results to date have not been encouraging. Dawson (1991a) notes "no species common in intensively gillnetted areas appears to avoid entanglement completely." Nelsen and Lien (1992) note solutions are possible regarding the marine mammal fishery gear problem, but suggest "cooperative investigations, including gear technologists and fishermen, as well as marine mammalogists and experts in other areas, such as engineering and acoustics" may be needed. (See also "Other Perspectives on Incidental Take" in Young et al. 1993.)

Several rather unique gear alternatives with lower bycatch rates than trawls or various artisanal gears rates have been reported in recent years. In Mexico, a new fishing device called the "Suripera" has been introduced into the inshore shrimp fisheries, reducing bycatch on the east coast of the South Sea of Cortes to 20% of that taken by traditional castnets (Chavez 1992). Further, the nets are reported to be three times more efficient than the traditional castnets. However, the author concludes by noting "the scarce information available about the fishery operations is not conclusive and full characterization of this net has to be done in order to assess accurately the conditions for optional operations."

In the Pohai Sea, a shrimp driftnet with "no bycatch was introduced in the early 1970s" (Ye 1992). The author notes that "with several years observation, the result with driftnets to fish Chinese shrimp is satisfactory." The use of pots as an alternative harvesting mode has also been suggested for the Australian northern prawn fishery and in the southeastern U.S. (Whitaker 1992; Buckworth 1992).

A clear example of the potential benefits involving a combination of fishermen training and technological solutions to a major bycatch problem is reflected in the efforts to reduce dolphin mortalities in purse seines in the ETP. Major advances responsible for the dramatic decline in the number of dolphins killed include development of the backdown technique and efforts spent to modify the design of tuna seines. Modification resulting from these efforts include (1) adoption of the Medina panel, (2) use of skiffs to prevent collapse of seines, (3) use of speedboats to prevent net collapse, (4) use of rafts and swimmers to release trapped porpoises, (5) optimized set orientation and background maneuvering,

(6) pear-shaped snap rings (National Research Council 1992), and (7) coordinated international education efforts (Platt, personal comm.). Recent estimates suggest the mortality imposed on porpoises caught in nets is only about two tenths of one percent (0.16%).

Ethical concerns and the decision of U.S. buyers to boycott tuna caught in association with porpoises has shifted sectors of the U.S. fishery from setting on dolphins to setting on logs or other floating objects and on free-swimming (non-associated) tunas. This shift has greatly increased the bycatch of juvenile yellowfin tunas and other fishes[47], and the current practice may have a greater biological/ecological impacts (Hall/IATTC pers. comm.) than continued fishing on porpoises using the improved methods noted above.

Regulatory-Based Solutions

Effort reduction

Short of an outright ban on fishing, no action would likely contribute more to the resolution of bycatch problems than the reduction of fishing effort. Many of the world's fisheries are overcapitalized and regulated under open-access regimes. All too frequently, open-access, overcapitalized fisheries move toward shorter and shorter seasons as available quotas are rapidly being exhausted by more and more effort. The pressure on each fisher to harvest as much fish as possible before closure leaves little time to search for "bycatch-clean" fishing grounds, thus reducing aggregate bycatch takes, or to sort through the catch carefully and return non-target individuals quickly to the ocean, thereby reducing discard mortality rates. As an extreme example of this characteristic, fishers participating in the one- to two-day "seasons" now typical of the U.S. Pacific halibut fishery fish their gear to the last possible moment before severing the longline gear as the fishing period expires. Large quantities of gear that can continue to fish are left in the water (Wade 1993).

Murawski (1993), Alverson (1992a), and others have advocated an overhaul of the fishery management regime, including extensive reductions in fishing effort to reduce bycatch problems. If fishery resources are overexploited by an overcapitalized fleet, the benefits of such actions are clear. With less effort deployed, non-target species incidental to target species harvests decline along with lower target species removals. Depending on the method of effort control, harvests might proceed at a reduced pace because the race for fish could be less intense. In such instances, since fishing would not be as frenetic, more time should be available to search for grounds with fewer bycatch problems or to improve the effectiveness of the sorting process. While the race for fish may have slowed, it remains a race. Consequently, lost fishing time is still lost money, and so the bycatch benefits derived from a slower pace may be less than hoped for.

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[47] Other fishes includes the catch of turtles.

The effectiveness of an across-the-board reduction in effort is less apparent when target species harvests are successfully capped by catch quotas. In this instance, reductions in effort will be associated with little, if any, drop in target species removals. Aggregate bycatch removals before and after the effort reduction may differ somewhat from one another. Only the potential bycatch benefits tied to a more rational harvest pattern can be expected to emerge. As already mentioned, the degree to which these benefits accrue is largely a function of how individual fishermen respond to the presence of longer seasons. If they use the time to improve their target to non-target catch efficiency, bycatch removals could drop significantly. If they instead remain focused on their goal of maximum target catch rates, changes in bycatch removals probably will not be observed.

To date, few effort reduction programs have been implemented successfully. This paucity can be attributed to a number of reasons, not the least of which have been the economic impact to fisheries, costs to government, and political opposition allocating public resources to selected individuals. However, bycatch concerns broaden the fishery playing field considerably. New groups, in addition to traditional industry interests, are becoming active participants in the decision making process. Their concern over bycatch and its potential consequences, be they real or perceived, have been an important reason for the elevated level of attention these new groups are directing at fisheries. If this attention leads to effective measures to deal with bycatch, such as effort reduction programs, these changes will carry considerable benefits for other aspects of fisheries management as well. Bycatch has always been an artifact of the fishing process, but it is perhaps naive to assume that overfishing and overcapitalization of fisheries will be resolved in the foreseeable future. Thus, it becomes increasingly important to focus attention on all possible alternatives for achieving reduction in discard mortalities.

Use of incentive and disincentive programs

A number of authors, including Iudicello and Leape (in press), Hughes (1992), and Thornburgh (1992), have suggested bycatch and discard problems can best be resolved through placing responsibility at "the individual vessel level." Hughes notes "Managers have many tools with which to regulate bycatch. Their favorite seems to be time and area closures plus mesh size." But he further notes

> More often than not, in Alaska, regulations which close chunks of fishing grounds to address some bycatch problem one or two years previously have created a multitude of new bycatch problems as a result of forced changes in fishery effort and normal yearly/seasonal changes in distribution and abundance of both target and bycatch species.

Hughes and others urge incentive/disincentive programs as a significant tool to reduce discard problems. Solutions are founded on the premise that given

incentives, individuals will use their knowledge of gear and the fishing grounds to reduce the capture of unwanted species and maximize their catch of target species. Incentive/disincentive programs are a means by which the choices of individual fishers can be bent towards improvements of bycatch and other management problems. While they do have their deficiencies, namely in complex multispecies fisheries where incentives and disincentives are difficult to clearly identify, they have been and are being used to reduce bycatch rates substantially.

Until the late 1970s and 1980s, the Japanese and other foreign nations had more or less free access to the large groundfish resources of the Bering Sea and Gulf of Alaska. After passage of the Fishery Conservation and Management Act by the U.S. in 1976, however, U.S. domestic groundfish fleets began to grow. Priority access to U.S. groundfish resources was granted to U.S. fishermen. Foreign fishers were left with only the amount of resource U.S. fishermen could not harvest.

Accompanying this restricted foreign access to U.S. groundfish resources was the opportunity for comprehensive data collection programs on board foreign fishing vessels operating in the U.S. Exclusive Economic Zone. Trained fishery observers were placed aboard all foreign groundfish vessels in U.S. waters, the first in-depth insights into the nature and scope of the bycatch problem in these fisheries.

As discussed in other chapters of this volume, bycatch in the North Pacific groundfish fisheries includes several species of crab, halibut, and salmon which form the backbone of other valuable fisheries in the region. Now that on-board observers were collecting information quantifying the extent of this bycatch in the foreign groundfish fisheries, these U.S. fishing industry groups clamored for tighter controls on the foreign operations. U.S. fisheries managers responded to these demands which called for foreign fishing nations to reduce their bycatch rates to agreed-upon rates. Failure to drop their rates to the agreed-upon levels meant either immediate expulsion from the fishery or a low chance for quota access when application was made for the next fishing season. Incentives to fish cleanly and stay in the fishery were clear. Perhaps more important, not only were the disincentives to reduce bycatch rates obvious, but there was also little doubt they would be enforced.

The response by the Japanese to this system of incentives and disincentives was remarkable. In the following excerpt from a letter from the Japanese Fisheries Association to the North Pacific Fishery Management Council,[48] it is clear when the incentives and disincentives are evident to individual fishers, significant improvements to the bycatch dilemma can be made:

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[48] Letter from Mr. Jay Hastings, Japanese Fisheries Association, to Clarence Pautzke, Executive Director, North Pacific Fishery Management Council. April 17, 1991.

The Japanese fishing master and captain for each vessel developed their own techniques for avoiding bycatch under Amendment 3.[49] These techniques were developed based upon the physical conditions of the fishery and within a management framework which both encouraged and permitted bycatch levels to be reduced. Fishing methods were modified depending upon current physical conditions surrounding the fishery. These modifications were conventional. They included adjustments in trawling depth and speed, gear modifications and shifts in fishing times and areas. The Japanese do not believe there are any particular techniques or secrets which can be explained to the Council. The modifications were the result of experimentation and years of experience in the fishery.

But we do note changes in the fishery and its management which are substantially different from the mid-1980s. It is our understanding that some of the bycatch resources have increased in abundance which may affect bycatch rates. But more importantly, the bycatch management framework within which the U.S. fleet operates is quite different from the framework within which the Japanese fleet operated. The Japanese government and industry developed an internal allocation management framework which forced a reduction in bycatch rates but allowed the Japanese vessels to make the necessary adjustments in the most efficient manner.

Under the Japanese management framework, the national allocation for each directed and bycatch species was first allocated among three Japanese vessel associations with member vessels licensed to fish in the U.S. zone. Each association would then further allocate each species among the member vessels on a vessel-by-vessel basis. This vessel allocation system forced each vessel to maintain its bycatch within the vessel allocation for that species. There was no common pool for either directed or bycatch species from which a vessel could fish and there was no internal reserve established to provide relief should a vessel exceed its allocation. If the vessel allocation was exceeded for any one species for which the vessel had an allocation, the vessel had to return to port.

This rigid self-imposed allocation scheme helps explain why the Japanese bycatch rates were so low. Japanese fishing masters had to be conscious of their bycatch rates at all times to keep the bycatch well within the vessel allocation and ensure an adequate margin of safety for continued vessel operations. Otherwise, the vessel could be prematurely eliminated from the fishery with only a few bad tows. The result was an accumulated savings by the entire fleet. Similar savings would not seem possible under the current system wherein the total bycatch only is monitored and the fishery is closed when that bycatch allocation is reached.

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[49] Amendment 3 to the Bering Sea/Aleutian Island Groundfish Management Plan mandated lower bycatch rates among the foreign fleet sectors.

A specific example may be more meaningful. In 1985 Japan received a 199 mt allocation of sablefish in the Bering Sea for bycatch only. This 199 mt was further allocated among the Japanese vessels licensed for the U.S. fishery. One particular smaller trawl vessel received an internal vessel allocation of 1.48 mt of sablefish for the entire year. The highest rate of incidence of sablefish, when taken, was experienced in the turbot fishery for which the vessel had an allocation of 508 mt. Through September of 1985 the turbot catch was 461.1 mt. Yet the total incidental catch of sablefish was only .84 according to the vessel reports and .695 according to the observer reports. By October 5th of that year the entire Japanese fleet had taken only about 56 mt of sablefish from the total 199 mt allocation. The system forced each vessel to minimize bycatch rates in order to ensure continued operations within vessel limits.

I can still recall severe internal repercussions resulting from this management system. If a vessel was approaching its bycatch allocation for a certain species, the pressure was really put on the vessel to make the adjustments necessary or leave the fishery when the vessel bycatch allocation was reached. Observer reports were also monitored carefully and we would immediately contact the observer program if we felt adjustments in the observer reports were warranted. It was also possible for vessel owners to purchase unused bycatch allocations from other Japanese vessels. But this opportunity was rare since the Japanese vessel operators did not want to give up any allocations received even though the vessel may have fished only a few days during the year. When all else failed, the vessel was ultimately forced out of the fishery when its allocation was utilized.

Although the system was severe on bycatch, it provided the opportunity for each vessel to develop its own fishing plan to ensure efficiency in the utilization of its allocations throughout the year. This opportunity was provided through the similar allocation of target species on a vessel-by-vessel basis. The Japanese management philosophy underlying this allocation system was to eliminate the competition for resources on the fishing grounds. Each vessel could develop its own season for fishing based upon a combination of marketing, resource and vessel allocation factors. The vessel could then pursue its fishery plan at its own pace without fear that target fisheries would be closed before its individual vessel allocations would be harvested.[50]

Of course, not all applications of an incentive/disincentive programs may be as successful as described above which draws on many aspects of the quota systems

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[50] Another example of an individual annual quota for dolphin has also recently been established for the tuna seine fishery operating in the ETP. The quota is parceled out to individual vessels. Target quotas may be adjusted annually upon review of progress within the fishery. For example, in 1993, deaths due to capture and release for tuna seiners were much lower than targeted, so the 1994 target for fishery incidental mortality was lowered 40%. Between 1986 and 1992 dolphin mortalities have declined 88%, while sets on dolphins during this period declined only 2% (Hall 1994, pers. comm.).

to be described in the following section. In complex multispecies fisheries it may simply be impossible to eliminate the bycatch of some non-target species. In some fisheries it may be difficult to find the appropriate mix of incentives and disincentives to achieve bycatch reduction goals. In still other instances, legal and due process realities may block the implementation of an effective incentive/disincentive program. Political maneuvering may impede the development of systems that are not only effective but are also fair. Furthermore, many require a comprehensive observer and data collection program that may be too costly to put into place in some fisheries.

What the example has shown us, however, is that if incentives and disincentives have tangible results for the individual fishermen, they have a good chance of working. The Japanese in the Northeast Pacific realized the penalty for failure to lower discard levels of halibut meant the elimination of an important source of revenue and protein. To them, it was far more costly not to reduce their bycatch than it was to act to improve their target/non-target catch ratios. The fact they were able to do so should not only be of great credit of the involved fishermen, but also be encouraging to those seeking a management strategy with a high chance of reducing aggregate bycatch removals while allowing the fishery to continue.

Individual transferable quotas

The opportunity for short-term economic gain is all too often at the heart of fishing practices that lead to waste and inefficiency. Long-term benefits that would accrue due to more restrained approaches are sacrificed for near-term financial opportunities. Next month's boat payments are of more immediate concern than next year's stock size or the fishery's viability the year after that. Thus commences the free-for-all race for fish. Every fish I do not catch today is one more left for the next vessel to harvest tomorrow.

Unlike open entry management systems, ITQs attempt to address head-on the challenge of the short-term perspective of most fishers. By relating tomorrow's fishing opportunity to today's actions, ITQs begin to change the time horizons of fishers from short to longterm. In so doing, they may create the opportunity for resolution of the bycatch problem.

ITQs provide ownership rights to the fishery resource. As with other property, if it is well taken care of, its value will generally strengthen. If abused, its value may very well fall. ITQs are based on the premise that fishers who own a portion of the fishery resource will be prone to use it in a manner enhancing rather than detracting from its value. Effort limitation and all of its advantages are a necessary part of a successful ITQ program. The transferability of quota permits a distribution of fishing access to those who best can use it and to dismiss excess effort in favor of economic efficiency.

Although few ITQ systems have been implemented, those which are in place have been generally successful, aside from an often stormy period of transition and adaptation to the new approach. New Zealand's ITQ system is the broadest to date. While opinions differ on how successful it has been, it is generally agreed the system is working more or less as intended.

Most ITQs have been designed with the control of target catch in mind. Nevertheless, ready application of ITQs to bycatch management can be made. ITQs for bycatch might not only control the aggregate discard levels but also permit the distribution of bycatch to the most efficient users of the resource. If a given vessel runs out of bycatch quota, additional amounts can be purchased from boats with quota remaining. Of course, as remaining bycatch quota becomes more scarce, the per unit value of that quota increases and the true value of bycatch to the fishing process becomes evident. Boats which have not fished cleanly are now forced to purchase bycatch quota at market values in order to continue to fish. Vessels which have experienced low bycatch rates throughout the fishing season have quota remaining either to sell or to use themselves until the quota or the target species catch levels are reached.

Bycatch ITQ systems are thus an amalgamation of effort reduction and incentive/disincentive programs. At worst, effort is capped in order to introduce an ITQ. At best, it is reduced through buy-back programs. Strong and unavoidable economic incentives emerge to fish cleanly in order to continue to fish when other operations have been terminated. Disincentives linked to lost fishing opportunity are also obvious.

Unfortunately, there are also downsides of ITQ systems. Management and regulatory costs associated with them can prove expensive. Opportunities for entry of young fishers may be limited by the high costs of obtaining the necessary permits and quotas. igh-grading and mislabeling can be considerable. So the applicability of an ITQ system and its contribution to bycatch reduction must be assessed on a case-by-case basis.

But because of its inherent advantages (an implicit drop in fishing effort, tangible bycatch reduction incentives, definition of the true costs of bycatch, a transition from a short- to long-term planning horizon), from the perspective of reduced bycatch, ITQs appear to us to be an appropriate management strategy if they can be properly managed and enforced. Clearly, effort reduction and significant gains in lowering bycatch could be achieved, but without adequate incentives or disincentives, the success of effort reduction programs will be incomplete. And finally, if fishers perspectives remain on the shortterm, battles will continue to be fought about the appropriateness of particular incentives and disincentives.

This integrative capability makes ITQs all the more difficult to put into place. Managers who attempt to do so are attempting to bring not one or two

pieces of the puzzle together, but rather the whole package. To do so successfully will require as much cooperation and consent from industry and non-industry groups and as little self-serving political maneuvering as possible.

Time/area solutions to bycatch and discards

In addition to bycatch reduction resulting from the employment of appropriate mesh, hooks, net designs, new fishing gears, and improved fishing methods, several authors suggest reductions in discards can be achieved through time/area control of fishing activities. It has been observed the collective experience of fishermen provides them with an opportunity to allocate their fishing activities in a manner that could significantly reduce bycatch levels (Alverson 1992a; Marasco and Laevestu 1992; Murawski 1992; NRC 1991a; Wilson 1992). The ability of fishermen to extract species from their environment at rates far in excess of their relative abundance in the biological community and to minimize bycatch of much more abundant species is reflected in Table 41, providing information on the percentage of target species taken in the catch versus the percentage of the demersal fish biomass each target species comprises in the Bering Sea. For example, the large-scale pollock trawl fishery in the Bering Sea on average captured 99% pollock with less than a 1% bycatch (in 1992), while as a species it constituted 42% of the demersal fish biomass. Fishermen targeting on Greenland turbot catch, on average, 64% turbot in the nets, although the species constitutes only 2% of the bottomfish biomass.

Table 41. Relationship between demersal fish biomass and catch of target species. Source: NRC data files.

Target Species	Target Species Percent of Total Catch in Each Target Fishery	Percent of Overall Demersal Species Biomass
Pollock	99%	42.0%
Yellowfin sole	67%	16.0%
Cod	72%	5.0%
Rock sole	56%	9.0%
Pacific Ocean perch	16%	0.9%
Greenland turbot	64%	2.0%

Adlerstein and Trumble (1992) suggests that "time/area management can work under proper circumstances. It is most effective if a species (or complex) will clearly be absent from an area." However, he also notes that "to the degree overlap occurs of protected species, the effectiveness of time/area closures declines."

The report also observes that diel differences in distribution may sharply alter bycatch rates (Adlerstein 1992; Clark 1990).

Murawski (1992) notes the main objective of time/area management strategies should be to "take advantage of naturally occurring varieties in the degree of co-occurrence between target and bycatch species." However, most authors, including Murawski, conclude "in practice it has been difficult to establish fishery times that will consistently meet the bycatch objectives." In addressing the use of time/area solutions, Murawski (1992) concludes:

> Any bycatch reduction plans involving time/area manipulation of the fishery must address the following considerations: (1) Will the proposed solution be economically viable? i.e., the bycatch problems may be mitigated, but the fishery may not be profitable. (2) Does the proposed solution result in consistently lower bycatch rates? (3) Can the program be effectively implemented and enforced?

Closed areas are used in many parts of the world to control bycatch mortalities. However, the contribution or effect on overall mortalities has only infrequently been addressed. Rijnsdorp and van Beek (1991) have evaluated the introduction of the "plaice box" in an area of the North Sea closed to trawling spring and summer. The report states "the plaice box in the German Bight, installed by the EC in 1989 to protect undersized plaice, has a beneficial effect on the survival of undersized soles." The expected gain[51] in sole recruitment resulting from the closure is estimated at 11%, and 14% if the closure were extended throughout the year. Chapter 9 notes a somewhat different consequence of a similar "cod box" which led to little evidence of conservation gains. Trumble (1992) states closed areas to foreign fishermen in the Bering Sea had little impact on bycatch rates.

Regulation of fishing methods

Reductions in bycatch and discards may also follow implementation of regulations based on public, political, or managerial views that observed levels are unacceptable because of (1) the perceived biological or ecological impacts to ocean resources or the environment, (2) economic impacts generated by one sector of the industry on another, and (3) ethical concerns. The establishment of a series of declining bycatch quotas in the U.S. purse seine tuna fishery in the ETP reflected both conservation and ethical concerns. Elimination of the high seas driftnet fishery involved perceptions of waste and conservation and ecological issues, as well as ethical concerns. Results in such instances may be dramatic in terms of bycatch reduction, but also devastating to the involved user groups.

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[51] Assumes 100% survival of fish through webbing, but suggests survival between 60% and 100% for fish passing through trawl webbing. The authors conclude extension of the closure to the southern and southwestern North Sea would about double the plaice recruitment. Impacts of the closure on the trawl fisheries in general, however, are not reported.

Regulatory reduction in bycatch levels may also take the form of established bycatch quotas for various sectors of the fishing fleets. In the Northeast Pacific, Gulf of Alaska, and Bering Sea, discards of certain species characterized as prohibited species are mandated by law to prevent "the surreptitious targeting of those highly valued species" (Wilson and Weeks 1992). For each identified prohibited species, such as salmon, halibut, crabs, and herring, sectors of the fleet have been allocated "prohibited species catch" (PSC). When the PSC is reached for a particular target species in a regulatory area, the fishery is closed, thus requiring the offending fleet to seek access in an alternate area or to terminate fishing activities. The socio-political discord between competing sectors of the fleet is often minimized by this approach, but the overall economic benefits that might flow from the fishing area may be significantly reduced (Amjoun and NRC 1991; Marasco 1992; Wilson and Weeks 1992). Further, the required discard of significant numbers of dead fish having high or low market value is considered by many users as socially unacceptable.

Although reduction of bycatch through gear elimination or fixed quotas may seem harsh to some sectors of society, it is deemed a necessary step by others to achieve their conservation and environmental goals. Iudicello and Leape (in press), in a paper examining regulatory measures for controlling bycatch, state:

> From the conservationists' point of view all the organisms in the sea have a value--in place inchoate. In our view there has yet to be recognition that bycatch is a symptom of a larger problem: a fishery management system that is still in the development mode when it is time to be in the precautionary mode.

Finally, the amounts of discard may be aggravated by regulatory regimes which (1) use time/area controls to mitigate losses to one species, but do not consider bycatch and discard effects on other species in more intensely fished alternate areas or in the same areas by alternative fishing gears or methods, (2) allow fishing effort greatly to exceed that required to attain sustainable annual harvest levels, (3) allocate catch of a particular species to a single gear type without regard to, and the time/areal catch composition of, different gear types, and (4) promote "Olympic" type fishing activities.

Discard reduction through use of a broader spectrum of the catch

Numerous authors (Murawski 1994; Alverson 1992a; Morrissey and Robles 1992; Thornburgh 1992; Andrew and Pepperell 1992; Gulland and Rothschild 1984; Saila 1983) have proposed that the discard problem can be resolved, at least in part, through broader use of the species being discarded. The solution to many world shrimp discard problems has focused on broader utilization of the discarded species (Snell 1978; Herzberg and Shapira 1978; Elsy 1986; Barratt 1986; Mocking and Machava 1985; Luna 1981; Musuishi 1981; Peterson 1981).

Considerable attention to this approach has occurred in tropical ports of Asia, South America, North America (Mexico) (Pauly and Neil 1992; Blake and Bostock 1991; Gordon and Blake 1991; Gordon 1991, 1988; Suwanrangsi 1988, 1986; Ordonez 1985; Bung-Orn 1982; Lemoine 1982), and historically in the fisheries of Asia. Nevertheless, this pattern has been deteriorating throughout much of Asia as more modern large shrimp vessels have been introduced into the fisheries of this region.

Ames (1993, pers. comm.), observing the expanding use of discards in world shrimp fisheries, comments:

> Our work with the Bay of Bengal (Blake, Bostock, Gordon, etc.) was intended to clarify the economic feasibility of landing bycatch for sale, according to quality and size, as wet or dried fish or crude fish meal. Women's cooperatives did the sorting, salting, drying, and marketing, but unfortunately the sale price of the product was not sufficient to cover processing costs and the minimum price paid to the trawlers.
>
> A different situation exists in Mozambique, where we are currently working. There has been a civil war in Mozambique for about twenty years, and there is a famine or serious food shortage in much of the country. Any quantity of fish, even a small batch of mixed species, can be sold readily, and there is a particular need for dried fish which can be transported inland. Shrimp trawling provides one of Mozambique's few sources of foreign exchange. Clearly, in this context landing the bycatch would help to meet the country's major needs. Accordingly, DANIDA is providing collector boats to bring bycatch ashore.... The bycatch is partly salted at sea and then it is landed at processing stations equipped with salting tanks and drying racks. The dried fish is sold at a profit, and there is clearly an unsatisfied demand for it.... Experienced fishermen seem very willing to take over the boats on contract. Since the DANIDA/ODA project was planned (in about 1986), fishermen with canoes have started to collect bycatch, and this is evidently more profitable than fishing. Dugout canoes go out to the trawlers and bring back quantities of up to 500 kg of bycatch. Traders buy the landed bycatch on the beach, for sale locally as wet fish or for salting and drying.

Since 1983 in northern Madagascar, FAO has carried out a small project for the utilization of bycatch assisting the coastal communities to collect the bycatch at sea and process and market it through traditional channels (Teutscher 1994, pers. comm.).

Expanding species use or utilization of smaller size fish could, on the other hand, negate certain conservation goals of management agencies if overfishing is already a problem for directed or non-target species or if the bycatch mortality is resulting in undesirable changes in the biotic complex of a region. There is also the ecological debate of whether discarding is a problem in terms of environmental

degradation or whether discarding supports unnatural food supplies for certain marine populations.

Chapter Summary

In searching for measures to reduce levels of discards, all the tools available, including regulation of gear, establishment of time/area fishing patterns, adoption of new technologies, rationalization of management regimes, and overall control of fishing effort, must be considered. It is unlikely any single approach can be universally applied. In our view, national and international adoption of one single principle will go further and deal more expeditiously with the global bycatch issue than any other combination of possible solutions, that is, to reduce effort on overfished stocks. In this respect, Murawski (1993) notes: "One contributing factor to the seriousness of some bycatch problems is that in some cases whole communities of resources are subject to systematic overfishing." The reduction of overall effort in these situations will not only improve yields of target species, but will also reduce the mortality on non-target species.

In the review of the Northeast Atlantic bycatch problem presented in Chapter 7 of our report we observe:

> An alternate approach [other than gear, etc.] to bycatch problems may be using direct conservation measures (reduction-in capacity, effort of catch) to reduce the load of fishing mortality on target and incidental catches alike. This may be sufficient in some cases to reduce the impact of the bycatch to acceptable levels. In other cases it may increase the profitability of the fishery and serve to reduce the rate at which fishermen discount future benefits and losses. This approach may increase the time horizon of fishermen who may find technical measures more acceptable. Thus, this approach may increase the acceptability of measures intended either for the long-term benefits of fishermen or the marine environment.

Considering the current state of world fisheries and the obvious significant increase in the numbers of overfished stocks, many suffering from growth or recruitment overfishing (Figure 17) (Alverson and Larkin 1992; FAO 1992b; NOAA Status Report 1993), the highest probability of a significant short-term reduction in bycatch would seem to result from the conservation of currently overfished stocks, in particular those subject to growth overfishing.

Nevertheless, we urge that managers and nations seeking solutions to bycatch problems consider carefully the full spectrum of management options available. Governments should concentrate on an aggressive program and develop harvesting technologies, incentive/disincentive programs, and other strategies reducing harvest levels of unwanted or prohibited species, and discard mortalities. The record also clearly reflects sustained bycatch reduction involving development

of new gear types is unlikely to come easily and must be based on (1) a fundamental understanding of the behavioral differences of species and the mechanical differences in the sorting that make selection possible, (2) operation requirements and limitation of vessel operators, (3) time, space, and environmental changes which may influence the nature of the results, and (4) persistent and dogged pursuit of the objectives (Pikitch 1992).

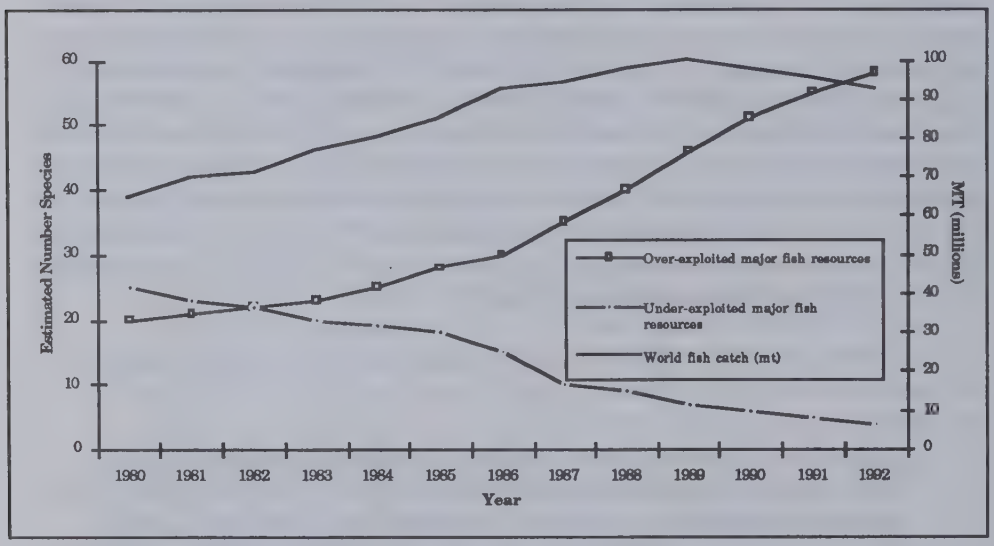

Figure 17. World fish catch (metric tons) and numbers of overexploited and underexploited species, 1980-1991. Source: FAO and NRC.

CHAPTER 10 DISCUSSION AND COMMENTARY

Over the past fifteen years, bycatch has become a topic of discussion in a variety of scientific, technical, and political forums. It has emerged as the "fishery management issue of the 1990s" (Tillman 1992). It is, therefore, somewhat ironic that the term "bycatch" is so frequently undefined and misused by managers, politicians, advocacy groups, and frequently even fishery biologists. Its contemporary application among most of these groups is generally synonymous with the capture and discard of marine life by fishing fleets resulting in waste, unreported fishing mortality, and threat to the survival of populations of birds, marine mammals, and other sealife.

The definition of "bycatch" used in a vast majority of technical/scientific papers, often the factual bases for formulating conclusions on the extent of biological loss and unreported catches, is all species captured other than target species. Thus discards may constitute a small-to-significant fraction of the identified bycatch, depending on the nature of the fisheries and local customs. For example, Andrew and Pepperell (1992) and the authors of this paper estimate the upper range of bycatch taken in the world shrimp fisheries to be in excess of 16 x 10^6 metric tons.

Yet throughout much of Asia and many of the world's artisanal fisheries, a variable share of the shrimp bycatch may be species retained for food or industrial purposes. Although discards in tropical shrimp fisheries are generally high, it is considerably less than the total reported bycatch, so it is important not to associate estimates of total bycatch with world discards of marine fishes. Further, discard rates and numbers may misrepresent the impacts because for a number of species some fraction of the discard survives. Without good estimates of the biomass discarded, the fraction of which survive, unobserved mortality and other fish-related losses, and the landed catch of a particular species, it will be impossible to assess overall impacts of fishing. We need to know the portion of the natural turnover which is killed.

The codification of international bycatch and discard policies, which vary regionally, has in many instances been in response to conservation and environmental groups concerned with impacts on marine mammals, turtles, and seabirds. In this respect, the impacts may only indirectly involve discard rates; rather, the quality of the bycatch and discards, including issues of ethics, may sharply influence regional policies. Further, regional policies on bycatch and discards may also be more concerned with socio-political or socio-economic consequences of selected discards than with overall bycatch rates of a particular fishery.

In some instances, regulatory policies appear to have been emotionally driven (Burke et al. 1993; Miles 1992a) and developed in the absence of available scientific evidence, while in other instances, actions taken to curb discards resulted

in counter-intuitive results. Nevertheless, the magnitude of the problem and the potential range of the consequences have brought bycatch and discards to the surface as a legitimate management issue requiring serious national and international attention. To date, most bycatch policy has focused on high-profile species, marine mammals, birds, and turtles. However, in the past several years, policy development has included issues involving biological and ecological impacts, biological waste, and economic losses.

In order to achieve a global estimate of discard, we have at times been forced to use total reported bycatch estimates and from these data "back-out" rather subjective estimates of retained species. Our best estimates suggest the global discard is 27.0 million mt--a rather staggering amount. This number may be an underestimate in that world recreational fishery discards are not included, the database for most areas of the world is incomplete, and discard weights are not included for marine mammals, seabirds, and turtles, and for many areas, the discard of invertebrates. The discard ratios and rates are likely to appear excessive to many readers, but it is not the intent of the authors to condemn those who harvest the oceans' living resources. However, it has been the authors' goal to clarify the character of world bycatch problems and where possible provide information that may be helpful to managers examining potential solutions. The level of losses for many fisheries may not be particularly excessive in light of other industries, based on the use of natural resources (NRC 1990). Rather, it is apparent a substantial opportunity is available for improvement in utilization of marine living resources and protection of overfished, threatened, or endangered species.

The potential for errors in calculating estimated bycatch and discards is enormous in light of reporting procedures in which some equate bycatch with (1) total discards, (2) secondary target species and discards, and, (3) selected species within the bycatch complex. Different operational definitions and failure to define what sector of the bycatch is involved may have in some instances complicated our analysis and made calculations less precise.

Although the major objective of our study has been to estimate regional and global levels of bycatch and discards, we recognize a considerable portion of the report deals with northern temperate fisheries. This was not the intent of the authors, but acquiring data from many developing areas of the world proved difficult. Our estimates are based on numerous research and observer records made throughout the world. Nevertheless, there is a paucity of data from many regions, and many observations involve data taken over short time spans by a small fraction of the fleets or even single sampling efforts made by research vessels. Further, the quantitative data used spans a number of years and may not accurately portray the present situation. These and other data problems noted in Chapter 1 of this report make it frivolous to attempt to establish hard statistical parameters around regional and gear type estimates. In reality, the estimates constitute "snapshots" based on collages of observations having various degrees of reliability taken over different seasons and years. The ultimate understanding of the true scope, distribution, and

magnitude of the bycatch and discard problem will require extensive documentation and acquisition of additional data from many regions of the world.

Thus, we urge our global and regional discard estimates be used as a provisional "best guess" of the potential magnitude of the discard problem resulting from fishing in the world's oceans. Further, we would hope this "best guess" will stimulate fishery researchers to collect and report adequate data leading to a more precise estimate. It must also be recognized that some portion of discards survive and thus are not lost from the ecosystem. In terms of finfishes, we see little evidence discard survival constitutes a significant portion of the discard for many commercial and recreational finfish species. Nevertheless, survival of flounders, dabs, invertebrates, and fishes not affected by rapid change in depth shows some promise for improved survival under constrained operational practices and appropriate handling (Pikitch 1993, pers. comm.).

During the conduct of the study, the authors became increasingly interested in the current total biomass of fish and shellfish removed from the world's oceans or killed as a result of fishing activity. Current world catch data suggest landings of about 98 x 10^6 mt (FAO 1992). These landings are frequently gauged against scientific estimates of potential sustainable yield of conventional species from the world's oceans' wild stock of about 100 x 10^6 mt. As a result, a number of authors have noted current world landings approaching the estimated maximum sustainable yield for world marine fisheries.

In making such reflections, such authors frequently fail to recognize this global catch total includes freshwater and aquacultural production. On the other hand, current reported world commercial fisheries landings do not include (1) discard mortalities involved in commercial fisheries, (2) recreational fish catches and bycatches taken from marine waters, (3) fish killed as a result of contact with fishing gear, that is, mortalities resulting from fish passing through net webbing or resulting from hooking of fish which subsequently escape, (4) ghost fishing mortalities, (5) under-reporting, (6) substantial subsistence catches and discards, and (7) landed catches of commercial fishes which are not purchased (rejects).

Using the 1990 landing report for marine fishes (FAO 1992b), about 83 x 10^6 mt and a discard figure of levels of approximately 27.0 x 10^6 mt, we arrive at a world marine catch of 110 x 10^6 mt without considering the six other noted categories involving fishery-related mortalities in marine waters. Even though a significant fraction of discards may not involve marketable species, it seems very likely the aggregate fishery deaths from fishing may be significantly over the sustainable yield estimates of 100 x 10^6. Of course, the 100 x 10^6 mt questioned by many scientists may be unrealistic, but in what direction? The point raised, however, is the total marine losses resulting from fishing is much greater than suggested by landing records.

The consequences of bycatch and discards, varying between regions, include (1) significant biological waste, (2) biological overfishing of target and bycatch species, (3) economic losses imposed on target fisheries, (4) modification of biological community structures in ecosystems, and (5) impacts on severely depleted, threatened, or endangered species. These impact categories are similar to those outlined by Fowle and Upton (1992) at the International Conference on Shrimp Bycatch.

Results of this study suggest scientific evidence does exist to support assertions that significant biological losses and ecological shifts in the biotic communities occur as a result of bycatch. Reports of bycatch suggest major bycatch and discard problems occur throughout the Atlantic. Other fisheries of the world having high discard rates include (1) most tropical and subtropical shrimp fisheries, (2) trawl and seine bottom fisheries, as well as northern shrimp and *Nephrops* fisheries in the North and South Atlantic, (3) tuna seine fisheries in the ETP which set on logs,[52] (4) North Pacific king and Tanner crab pot fisheries, as well as the yellowfin sole and rock sole trawl fisheries, and (5) a variety of pot fisheries for invertebrates throughout the world. For many of the above-noted fisheries, discards may equal or exceed in number or weight the quantities of what is landed and marketed. In total, millions of tons and billions of dollars of loss probably occur as a result of accidental capture and discard of unmarketable and marketable species. Much of the world's discarded fish appears to be small juveniles of commercially important species which, if left to mature, would produce significantly higher weight yields compared to the discarded weight. Finally, fishing discards impact a broad range of aquatic species other than finfish and shellfish species.

In the Northeast Pacific, the added fishing mortality resulting from discards does not appear significant for most gadoids, flounders, and other species, but the impacts of trawl, trap, and line fisheries on halibut is relatively large (about .08) and in terms of the allowed fishing mortality is about 0.3. Further, the potential impacts of the king and Tanner crab pot fishery on king crab populations may be significant, depending upon discard mortality. Reeves (1993) suggests Bering Sea red king crab discards amounted to about 16 million animals in 1990, more than five times the number landed. Many of these discards are sublegal (juvenile) individuals. The economic and biological implications of these discards, depending on discard mortality, may be a serious problem for red king crab stock dynamics and management.

In undertaking our study and discussing bycatch and discard problems with various elements of the fishing industry throughout the world, it quickly became apparent most commercial and recreational fishermen see bycatch as a problem confronting other gear types and user groups, but not themselves. Each user group tends to place itself on "high moral ground" and see other groups as the "culprits".

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[52] Tuna purse seine fisheries setting on dolphins has a very low bycatch-discard ratio while school fish sets have an intermediate bycatch-discard ratio.

Further, most had strong personal feelings on the "dirty" character of various fishing gears, although few had ever seen or reviewed data on bycatch and discard rates, either for their own or for other fisheries.

The authors, too, had somewhat tainted and preconceived views regarding the magnitude of bycatch and discard rates we were likely to find for various fisheries. We were somewhat surprised the low bycatch and discard rates by gear type frequently involve high seas driftnets, both by weight/weight and number/number ratios. We noted the highest discard rates per number of squid taken, observed for the Japanese squid fishery, is 0.37, lower than for any other reported high gear-type fishery noted in the world except for American lobster pots (.22). Further, number-based bycatch rates for the remaining driftnet fisheries are lower than rates for all other gear-type fisheries throughout the world. High seas driftnet fisheries were commonly listed among the lowest observed bycatch rates by number.

Of course, we were not surprised by the high discard rates for shrimp and some trawl fisheries, but did not expect the very low discard rates for midwater trawls and the very high discard rates of sublegals in many invertebrate pot fisheries. With few exceptions, high and low rates occurred for each gear type, depending on area and times.

The fact that actual observations are often at odds with public perception is not surprising and is a reminder the perception of a gear's impact and whether it is "clean" or "dirty" has a strong qualitative overtone, in many instances, in terms of the character of the bycatch discarded. High seas squid driftnet fishing was in reality being condemned because of the take of birds, marine mammals, and turtles (some of which were considered endangered), plus the association with illegal salmon fishing in the areas to the north of the squid grounds. Further, documentation of the fishery was not transparent to other interested nations. Some of the phrases and words used to describe high seas gillnetting by the press have little basis in fact for many high seas driftnet fisheries. Nevertheless, they served to rally national and international political support to condemn the gear and have its use prohibited in ocean space beyond national jurisdictions. At the same time they created a perception that driftnets and gillnets are destructive fishing gears wherever they are deployed. As a consequence, driftnets and gillnets are now being condemned in areas under national jurisdiction, regardless of the character of their bycatch.

It is important to recognize the ratio of discarded catch to the retained catch frequently may have little to do with observed and documented biological or ecological impacts. Such impacts must be evaluated on a case-by-case basis in terms of the discard mortality imposed on target and non-target species populations. Low bycatch and discard rates may still generate serious impacts, particularly if the fisheries of concern involve significant and geographically dispersed fishing effort. Note, for example, the observed bycatch rate for turtles in the Gulf of Mexico and

Southeast U.S. shrimp fisheries is very low and the actual encounter of turtles in the nets an infrequent event. However, the take in number of animals may be several tens of thousands, resulting in a discard mortality on turtles exceeding all other sources (Tillman 1992; National Research Council 1992).

Conversely, large observed bycatch of a species by number or weight may not constitute serious biological problems. For example, the large discard of pollock in the Bering Sea involves a very small fraction of the pollock population (on average $<1\%$ of the exploitable biomass), and managers require the bycatch take to be tallied as a part of the authorized harvest. However, a much smaller catch of halibut in the same region by trawls, line, and pot gear has constituted a serious loss of fish that could be taken in the halibut line fishery. For both species a significant economic loss occurs to the involved fisheries.

The data suggest generic characterization of gear types as "clean" or "dirty" may easily run into counter-intuitive results. Note, for example, in the Bering Sea groundfish fisheries the discard rate for trawlers, on average (.15 kg/kg) is considerably lower than the average for longline fisheries (.22 kg/kg), yet just to the south in the Gulf of Alaska, the average discard rate for line fisheries is about the same as for trawls (.21 kg/kg for both gear types). Further, inter-gear observations may change from year to year.

Impacts of bycatch and discards at the population level must take into account numbers and weight discarded and the survival of the discards and equate the discard mortality in numbers or weight to the subject population. In this regard, the terms "dirty" or "clean," based on observed rates, are rather meaningless, except as they may relate to the issues of biological wastage. Bycatch and discard problem represents too complex an issue to classify it neatly as "good and bad" or "clean and dirty," based on ratios of discards to retained catch or on numbers, weights, or other absolute indices. Unfortunately, such classifications, combined with the "spin" placed on reported numbers or weights of discards by advocacy groups, the press, and politicians, often serve to condemn a particular fishery or gear and frequently may result in generic condemnation of such gear or fishery without regard to biological/environmental, economic, and cultural impacts. Further, this process is too often blemished by inaccuracies and misrepresentation of facts.

Taken out of context, a discussion of millions or billions of fish or thousands or millions of metric tons of catch serves as a powerful motivator of public opinion which, in turn, has a considerable impact on the evolution of fishery policies.

Efforts to find solutions to reduce bycatch and discards and maintain fish production have, in the past, involved the development of alternative technologies, time-area fishing patterns, incentives and disincentives, and the greater use of species taken. In greatly overcapitalized fisheries and those in which growth

overfishing is obvious, the importance of controlling overall effort as a means of reducing bycatch and discards is apparent. However, the authors note quick, "easy-fix" solutions are unlikely and a dedicated national and international effort will be necessary to secure important conservation and economic goals associated with bycatch. Bycatch and discard reduction efforts should involve a clear and focused understanding of actual impacts and desired results. Reduction in bycatch for species suffering from overfishing or otherwise threatened or endangered should rank high among international goals.

In conclusion, the authors paraphrase the concluding observations of Iudicello and Leape (in press), in their paper entitled, "Regulatory Means for Controlling Bycatch."

> There needs to be a shift in the approach and accountability (in fisheries management): (1) Fishers need to prove that their current levels of bycatch in the short-term are unavoidable, and (2) management agencies need to use tools currently available and accept discarding as a problem to which government assistance should be directed. If conservation groups, governments and fishing groups commit to finding solutions, and there is a force of law behind policies directed towards reduction of discarding, a comprehensive program including (1) reduction in fishing on overfished stocks, (2) a combination of incentives and disincentives, and (3) new technologies as well as other alternatives could lead to significant reductions in the level of world's discards.

Finally, there is a growing global recognition that the world's fishing effort already exceeds what is necessary to harvest sustainable yields of marine fishes. The single action that will provide the greatest improvement to the bycatch and discard problem will be the reduction of these efforts levels. Without such control, other solutions to the bycatch and discard problem will be less effective and real success in our efforts to better manage the ocean's resources much more difficult.

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BYCATCH DATABASE

Instructions for Users

Two versions of the Bycatch Database, collected by National Resources Consultants, Inc., are presented in one MS-DOS diskette together with a text file (README.TXT) containing this note. The BYCDATAA file includes the complete database with the records organized in 23 fields. The BYCDATAB file is a summary of the complete database, it includes only a part of the records and 10 fields. The databases are in the Excel format (.XLS) but can also be imported in other software.

1. Description of Complete Bycatch Database (BYCDATAA.XLS)

Column A:	Count (serial number)
Column B:	Period
Column C:	FAO Fishing Region[1]
Column D:	Area of fishing[2]
Column E:	Fishing Nation
Column F:	Fishing gear
Column G:	Target species code
Column H:	Discard species code
Column I:	Discard in numbers
Column J:	Discard in weight (mt)
Column K:	Retained target species in numbers
Column L:	Retained target species in weight (mt)
Column M:	Discard number per target number
Column N:	Discard number per target weight (mt)
Column O:	Discard weight (mt) per target weight (mt)
Column P:	Summed discard number per target number
Column Q:	Summed discard number per target weight (mt)
Column R:	Summed discard weight (mt) per target weight (mt)
Column S:	Nontarget catch category
Column T:	Retained total per target
Column U:	Source reference number
Column V:	Report category
Column W:	Notes

2. Description of the Summary Bycatch Database (BYCDATAB.XLS)

Column A:	Species Name
Column B:	ICCSAAP Code

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[1] See next page for FAO Fishing Region codes.

[2] For the codes of column 4 to 8, see page 12 of the text.

Column	C:	FAO Fishing Region
Column	D:	1988-1990 average harvest total for species/area (mt)
Column	E:	Minimum discard ratio
Column	F:	Mean discard ratio
Column	G:	Maximum discard ratio
Column	H:	Minimum discard weight
Column	I:	Mean discard weight
Column	J:	Maximum discard weight

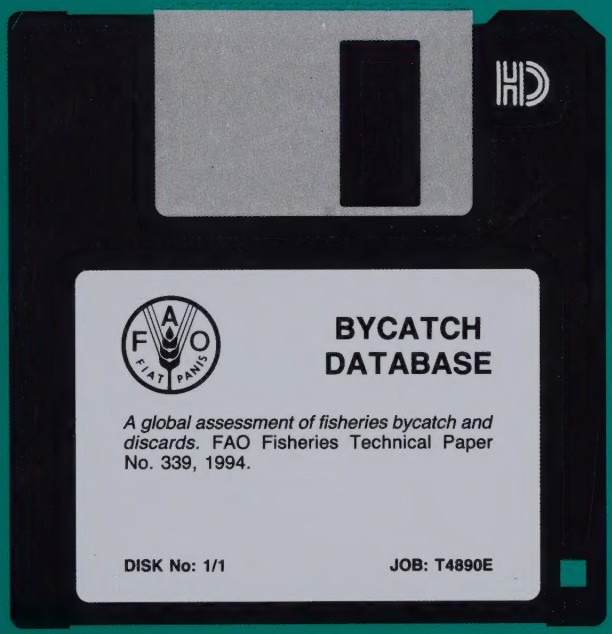
3. Discard Assessment Methodology

If minimum and maximun discard ratios are available, mean discard weights are derived from the average of the minimun and maximum discard weight. If minimum and maximum discard ratios are not available, mean discard weights are derived by multiplying mean discard ratio by harvest weight. In BYCDATAB, ratios in italics are best estimates of discard ratios. Values in bold in Mean Discard Ratio column apply to unidentified (Other) species in each ICCSAAP code and are intended to provide an indication of the level of discarding associated with the subject species group.[3] The ratios are the simple averages of observed minimum and maximum values for the same ICCSAAP code. For example, the mean value for ICCSAAP 34 is 0.2948. This was derived from the simple average of 0.022, 0.022, 0.33, and 0.805. The value 0.022 is used twice to account for its application as the minimum and maximum value for horse mackerel in the estimation process. Even though 0.022 was used as the estimate of horse mackerel discard ratios in several FAO regions, it is not used more than twice to derive the unspecified species mean. To use it more than twice would over-emphasize the importance of horse mackerel in the mean estimate, an estimate that is intended to be an index of all ICCSAAP 24 species other than those specified by name.

FAO FISHING REGIONS

Code	Fishing area name	Code	Fishing area name
01	Africa - Inland waters	41	Atlantic, Southwest
02	America, North - Inland waters	47	Atlantic, Southeast
03	America, South - Inland waters	51	Indian Ocean, Western
04	Asia - Inland waters	57	Indian Ocean, Eastern
05	Europe - Inland waters	61	Pacific, Northwest
06	Oceania - Inland waters	67	Pacific, Northeast
07	Former USSR - Inland waters	71	Pacific, Western Central
18	Arctic Sea	77	Pacific, Eastern Central
21	Atlantic, Northwest	81	Pacific, Southwest
27	Atlantic, Northeast	87	Pacific, Southeast
31	Atlantic, Western Central	48	Atlantic, Antarctic
34	Atlantic, Eastern Central	58	Indian Ocean, Antarctic
37	Mediterranean and Black Sea	88	Pacific, Antartic

[3] When BYCDATAB.XLS is imported in other software different from Excel, the italics and bold attribute can be lost.


BYCATCH
DATABASE
A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339, 1994.
DISK No: 1/1
JOB: T4890E

Based on a review of over 800 papers, the authors estimate that between 17.9 and 39.5 million (average 27 million) tonnes of fish are discarded each year in commercial fisheries. The highest quantities of discards aré from the Northwest Pacific, while tropical shrimp trawl fisheries generate a higher proportion of discards than any other fishery type, accounting for one-third of the global total. Data are inadequate to determine the biological, ecological, economic and cultural impacts of discards, although economic losses run to billions of dollars. It appears most likely that socio-cultural attitudes towards marine resources will guide international discard policies. Techniques to reduce bycatch levels, including traditional net selectivity, fishing gear development and time/area restrictions, are discussed. Effort reduction, incentive programmes and individual transferable quotas (which make the vessel responsible for bycatch reduction) are seen as promising avenues for the future. However, quick solutions to the problem are unlikely and much more information is required. The publication includes a diskette with the complete Bycatch Database, which was compiled for the study.

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